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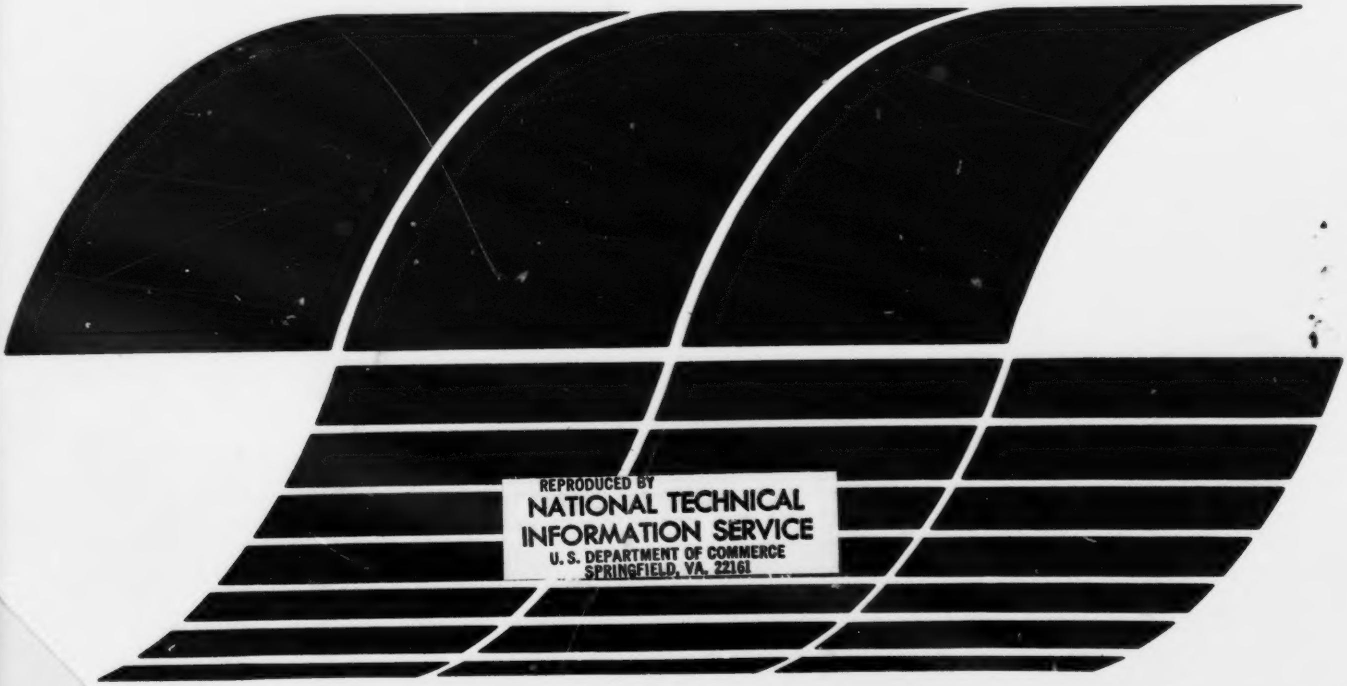
A Synthesis of the Available Knowledge

Interagency Energy/Environment R&D Program Report



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Substantially increased petroleum transfer and refining activities are anticipated in the northern Puget Sound and Strait of Juan de Fuca areas. These activities will likely increase the chances of chronic and/or acute oil inputs into the marine environment. These areas are currently stressed to only a limited degree by petroleum. The study reported here was undertaken to identify biologic means by which petroleum constituents may be transferred from lower to higher trophic level populations and to identify those populations and pre-predator links that are of critical importance to maintenance of major biological communities. Interruption of these critical links by loss of important prey groups could drastically change the composition and/or productivity of higher trophic level populations. The study was conducted by scientists at the Fisheries Research Institute, University of Washington, and involved primarily a compilation of existing data.

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A Synthesis of the Available Knowledge

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FOREWORD

Substantially increased petroleum transfer and refining activities are anticipated in the northern Puget Sound and Strait of Juan de Fuca areas. These activities will likely increase the chances of chronic and/or acute oil inputs into the marine environment. These areas are currently stressed to only a limited degree by petroleum. The study reported here was undertaken to identify biologic means by which petroleum constituents may be transferred from lower to higher trophic level populations and to identify those populations and pre-predator links that are of critical importance to maintenance of major biological communities. Interruption of these critical links by loss of important prey groups could drastically change the composition and/or productivity of higher trophic level populations. The study was conducted by scientists at the Fisheries Research Institute, University of Washington and involved primarily a compilation of existing data.

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I. INTRODUCTION

A principal concern about the long-term effects of oil spills in the marine environment is the fate and effects of petroleum hydrocarbons transferred through food web pathways and of the disruption, through toxic effects, of important food web linkages, causing significant alterations in the overall community structure of the biota. In 1977 MESA contracted the University of Washington's Fisheries Research Institute to document the structure of the marine food webs of northern Puget Sound and the Strait of Juan de Fuca using data from the literature, from unpublished sources, and from the ongoing MESA studies in the Strait of Juan de Fuca. This report is intended to synthesize all the information available on the food organisms, feeding behavior, and trophic (predator-prey) relationships of marine organisms and to discuss the possible effects of an oil spill on these ecological relationships.

Long before completion of the Alaska pipeline, it became apparent that a sizable volume of crude oil from Alaska's North Slope would eventually have to reach the high-demand areas of the continental United States, especially the midwestern region and the northern tier states. At that time, only Long Beach, California, and Puget Sound, Washington, had deep-water ports capable of handling the deep-draft supertankers (125,000 DWT) that would transport Alaskan crude oil. Notification of eventual diminution of crude oil shipment from Canada to the existing refineries at Cherry Point in north Puget Sound further intensified political pressure to establish a western terminus in north Puget Sound.

Political pressure began mounting in 1976 to prevent establishment of an oil port in northern Puget Sound. Opponents to such a port cited the navigational hazards of traversing the narrow channels through the San Juan Islands and the risk of oil spill damage to the region's natural resources, and lobbied for location of a facility west of Port Angeles along the less hazardous Strait of Juan de Fuca. Political pressure culminated in a Washington state law, the Tug Escort Law, prohibiting tankers greater than 125,000 DWT from operating in north Puget Sound east of Port Angeles, and requiring tug escorts of tankers larger than 50,000 DWT. This law was eventually modified by the U.S. Supreme Court (ARCO vs. Ray) on 6 March 1978. Since then, however, the U.S. Coast Guard has declared temporary navigation rules prohibiting tankers greater than 125,000 DWT from entering waters east of Port Angeles. By that time, the State Legislature had enacted a law prohibiting construction of an oil port and pipeline terminus east of Port Angeles, which was vetoed by the governor. The controversy, however, moved to the U.S. Senate where Washington Senator Warren Magnuson won approval of a similarly constructed amendment (Public Law 95-136) to the Marine Mammal Act which was enacted on 17 October 1977.

Facing an almost complete lack of economic and environmental information about the north Puget Sound region, in 1974 Washington State initiated the north Puget Sound baseline study through the Department of Ecology which was designed to evaluate the oceanographic, biological, and economic resources of the region (Gardner 1978). The State also implemented studies of potential offshore and inshore oil transshipment systems and sites by the Washington Oceanographic Institute in 1974 (Ocean. Comm. Wa. 1974, 1975).

Recognizing the lack of knowledge of the biological communities and oceanographic conditions of the Strait of Juan de Fuca, the National Oceanic and Atmospheric Administration's Marine Ecosystem Analysis (MESA) Program initiated baseline studies in 1975 which sought to document the character and dynamics of the biological communities, the oceanographic conditions, and the existing pollutant levels, as well as to model probable oil spill trajectories in the eastern region of the strait.

Although subtidal marine environments have been shown to be susceptible to the effects of petroleum hydrocarbons (North, et al., 1964; Blumer, et al., 1971; Kolpack, et al., 1971; Sanborn 1977), it is the nearshore (littoral and shallow sublittoral) and surface water (neritic) habitats that are the most available to pollutant introductions and effects. Petroleum pollution has generally had the most dramatic impact on these environments especially in estuaries (Clark and Finley 1977). Thus, the MESA biological studies, like the earlier Department of Ecology baseline studies, focused on the biological communities of the nearshore environment. The results of the first three years' studies were reported in Simenstad, et al. (1977), Cross, et al. (1978), Nyblade (1978, 1979), Webber (1979), and Everitt, et al. (1979).

This report resulted from the need to synthesize existing knowledge of the structure of food webs in nearshore marine habitats of northern Puget Sound and the Strait of Juan de Fuca, in order to identify the potential transfer processes of petroleum hydrocarbons through the marine ecosystem of the region. The objectives of this investigation were to: (1) identify the food web structures of biological communities of neritic, shallow sublittoral, and littoral habitats; (2) document seasonal, site, and regional variability in food web structure; (3) identify important predator-prey linkages that could be disrupted by a pollutant, and the potential consequences of disruption to the community; (4) identify the main prey organism groups utilized by economically or ecologically important predators; and (5) identify food chains having the greatest potential for transferring pollutants to higher trophic levels.

In addition to nearshore habitats, we focused on sites of existing or proposed oil terminals--specifically, Cherry Point and Fidalgo Bay (March Point) in northern Puget Sound, Burrows Bay at the eastern end of the Strait of Juan de Fuca, and Port Angeles.

II. CONCLUSIONS

In general, existing information on the structure of food webs in nearshore marine habitats of north Puget Sound and the Strait of Juan de Fuca shows that food web complexity or "connectivity" increases with decreasing exposure, decreasing sediment particle size, and increasing deposition of algal and vegetative detritus. Greater food web diversity implies greater energy flow, although the efficiency of energy transfer may be less. Under some circumstances, the more diverse the food web, the less liable the overall community structure is to change dramatically as a result of removal or alteration of linkages.

Except in neritic food webs, detritivores are the major prey organisms leading to higher trophic levels in the region's nearshore ecosystem. Direct herbivory by suspension feeding and grazing on macroalgae is less important. The most important detritivores are epibenthic organisms such as gammarid amphipods, harpacticoid copepods, flabelliferan isopods, tanaids, mysids, and polychaete annelids, which are the principal prey of nearshore carnivores, fishes and shorebirds and seabirds. Neritic phytoplankton-zooplankton-planktivorous fish food webs effect more rapid, direct transfer of organic matter among trophic levels, whereas detritus-based food webs are typically more complex and effect slower transfer among trophic levels. Additionally, heterotrophic processing of autotrophically produced algal and vegetative carbon is a critical mechanism limiting the productivity and transfer rates of detritus-based food webs.

The effects of petroleum hydrocarbons would appear to be more pronounced and long-term on food webs based on detritus processing than on food webs based on herbivory. The incorporation of hydrocarbons into fine, unconsolidated sediments and detritus pools of contained embayments can result in prolonged recycling of persistent hydrocarbon components through the detritus-decomposer-detritivore food web, continually providing contaminated epibenthic prey to the upper trophic levels, including species utilized by man.

Except for the neritic habitats, the majority of nearshore habitats in north Puget Sound and the Strait of Juan de Fuca have food web structures which could be altered for years by the introduction of petroleum hydrocarbons. The contained embayments, eelgrass beds, and saltmarshes of north Puget Sound, however, have the potential to suffer longer from perturbations than the more exposed environs of the Strait of Juan de Fuca. The sand/eelgrass and mud/eelgrass habitats in the eastern Strait of Juan de Fuca are also sensitive to petroleum effects. Of the four areas of existing or planned oil terminal sites, March Point near Anacortes may have the greatest sensitivity to ecological disruption by oil spill because of the diverse communities and complex food webs characterizing the mud/eelgrass habitats which predominate there. Exposed cobble habitats at the other three sites have less complex food webs, and there is less chance of incorporation of unweathered oil into the more consolidated sediments. In these latter three areas, Cherry Point has the most diverse food web, followed by Port Angeles and Burrows Bay. The food web structure of the Port Angeles vicinity, however, showed the highest connectivity (average number of linkages per node) of any of the areas, including Fidalgo Bay.

In almost all instances, food web structures were most diverse--greatest number of nodes as well as linkages--during spring and summer. During these seasons diversity of food web was most pronounced in the neritic and some of the exposed cobble-gravel habitats where a multitude of marine organisms at several trophic levels spend their early life history before settling into benthic habitats or moving into the shallow sublittoral region. The larvae and juveniles of many economically important species, such as Pacific salmon, Pacific herring, and Dungeness crab, are also particularly prominent (and susceptible to toxic pollutants) during these seasons. Juveniles of many species, especially fishes, increase the diversity of food web structures characterizing the more protected habitats in spring and summer, and seabirds and shorebirds are responsible for maintenance of similarly diverse food webs in fall and winter. Because of the importance of juvenile recruitment for sustaining the adult populations and the greater vulnerability and sensitivity of juvenile forms to toxic petroleum hydrocarbons, food webs in spring and early summer have the greatest potential for disruption by spilled petroleum and its incorporation into the nearshore environments of the region.

A number of taxa or assemblages of organisms were identified as being critical to upper trophic levels, either because they provide food resources for important consumer organisms, or because they convert or transfer organic matter to trophic levels where it is available to higher level consumers, e.g., detritus processors. The two most obvious groups were calanoid copepods and gammarid amphipods. Calanoids are the key herbivores in the neritic food webs and the principal prey of important consumers such as Pacific herring, Pacific sand lance, and juvenile Pacific salmon, which in turn are the main secondary consumers utilized by higher level carnivores in that habitat. In the shallow sublittoral zones of the nearshore environment, gammarid amphipods head the list of detritivorous crustaceans which are the main food of nearshore consumers. Their conversion of detrital carbon into food biomass for nearshore fishes and shorebirds provides the principal structure for almost all of the nearshore food webs. Other detritivorous crustaceans such as harpacticoid copepods, flabelliferan isopods, cumaceans, mysids, and shrimps also contribute significantly to important upper-level consumers.

As a great number of the nearshore food webs are apparently supported by detritivores, the sources of detrital carbon are also of ultimate consequence in sustaining a productive biotic community. Although there have been no studies to estimate the relative contributions to the total annual detritus by kelps and other macroalgae, microalgae, eelgrass, saltmarsh plants, and riverine inputs, it would appear that eelgrass and kelps are the main sources in north Puget Sound and the Strait of Juan de Fuca. Riverine inputs, principally from the Fraser and Skagit rivers, may be more significant in the neritic habitats in north Puget Sound. The physical and biological processes of breaking down and conditioning these large organic particles into particles small enough to be used by the small detritivorous crustaceans have not yet been examined. They appear to be different in different habitats. Exposed habitats such as rocky and cobble littoral and gravel-cobble shallow sublittoral habitats may act as giant grinders, physically reducing the kelp plants to smaller particles. Contained sand/eelgrass and mud/eelgrass embayment habitats may act as detritus traps, where a pool of eelgrass and other organic particles decomposes primarily through microbial activity. In both cases the critical step of conversion to usable biomass involves microbial colonization and reduction (making more surface area available for colonization) of detritus particles.

While a number of specific food webs or prey-predator linkages were identified as prominent or important in the region's nearshore marine communities, several stand out because they form the trophic base of economically important species. The phytoplankton - calanoid copepod food web in neritic habitats forms the resource base for juvenile pink and chinook salmon and Pacific herring, all of which as adults support high-value fisheries. Calanoid copepods are also used by secondary consumers such as fish and crab larvae which are in turn consumed by juvenile coho salmon. Thus, for the critical period of their juvenile residence in Puget Sound during migration into the Northeast Pacific Ocean, three of the five species of Pacific salmon of this region are dependent upon this short, simple, but substantial neritic food web.

Pacific herring and the other major neritic secondary consumer, Pacific sand lance, subsequently form the principal food organisms of many recreationally or commercially important fish species (lingcod, rockfishes) of the rocky/kelp bed habitats, of resident Puget Sound salmon ("blackmouth," chinook), and aesthetically valued carnivores such as orca, Dall porpoise, and alcid seabirds. In the shallow sublittoral habitats, the detritus-detritivore, gammarid amphipod, harpacticoid copepod food web supports juvenile chum salmon and a number of juvenile flatfish (English sole, rock sole) which are commercially exploited as adults. The importance of the shallow sublittoral habitats, especially eelgrass, as nurseries and juvenile rearing environments for fish and invertebrates economically important in the Puget Sound region cannot be overstated.

III. RECOMMENDATIONS

Many lacunae in our data and in our understanding of nearshore community and food web structure were discovered during this analysis of the northern Puget Sound and Strait of Juan de Fuca region; some of them were glaring. For example, it is most unfortunate that there are no quantitative data on the species composition and food web relationships of the fish communities of the extensive rocky/kelp bed habitat in this region. Having no data comparable to those obtained during the DOE studies in northern Puget Sound severely inhibited our ability to evaluate the structure of the food webs characterizing the outer strait. The only available data were from Barkley Sound along the northwest coast of Vancouver Island and cannot be considered representative of the outer strait. Many of the fishes composing the communities of this habitat are important recreational or commercial species (lingcod, rockfish, greenling). SCUBA-diver transect studies such as conducted by Miller, et al. (1977), and Moulton (1977) are definitely needed.

The role of pelagic plankton as the base of the neritic food webs is obvious; the structure and dynamics of nearshore pelagic zooplankton communities are not obvious. Existing documentation of these communities in the region, including the MESA studies (Chester, et al., 1977), are oceanographic examinations of mid-channel, deep-water stations. Comparison of fish assemblages at such stations with nearshore assemblages suggests that the nearshore environs, and especially contained embayments, harbor much higher densities of neritic fishes and decapod larvae. There is an obvious need to determine the relationship between offshore pelagic zooplankton and those populations found in the nearshore neritic environment, whether the latter are an advected component of the former or a unique community characteristic of nearshore habitats.

The lack of data on the prey organisms of marine mammals and seabirds and shorebirds inhabiting north Puget Sound and the Strait of Juan de Fuca is apparent from reading Appendices C and D. Considering their important roles as secondary and tertiary carnivores and their ecological and recreational importance, quantitative documentation of prey composition and consumption rates are necessary before the magnitude of their predation upon lower trophic levels and their dependence on specific food web linkages can be properly assessed.

The importance of detritus in nearshore food webs is apparent, but studies of the decomposition process and the interaction between pollutants and organic detritus particles are completely lacking. We need a much better understanding of the mechanisms, rates, and rate-limiting factors regulating the microbial, chemical, and physical processing that make detritus accessible to detritivores and to incorporation into the food web. And although it has been established that detritus particles often adsorb hydrocarbons, the conditions dictating the processing and incorporation of the hydrocarbons by microflora and the transfer to detritivores are unknown. This crucial process must be examined before we can hope to understand the pathway of pollutants through detritus-based food webs.

The question still remains of whether a more diverse or connected food web is necessarily more stable--i.e., less prone to be severely altered by removal of a portion of its nodes and linkages--than a simpler food web. Efforts to answer this question have been only theoretical or through simulation modeling. As yet, no one has experimentally perturbed a documented food web in the laboratory or in the field by introducing a toxic substance and following the acute and sublethal effects through time. Similarly, although there have been a few laboratory experiments to examine the transfer of petroleum hydrocarbons between trophic levels, there is a need for more detailed, multi-trophic level experiments which include documentation of sublethal effects on the growth, behavior, and reproduction of secondary and tertiary consumers.

IV. MATERIALS AND METHODS

Synthesis of known food web relationships was made with information gathered through a combination of analytical, laboratory, and field sampling tasks, including (1) comprehensive quantitative analysis of existing raw data residing in NOAA/MESA and our own data bases; (2) review of published and unpublished literature and inclusion of appropriate data in the data base for analysis; (3) analysis of hitherto unprocessed fish stomach specimens from the north Puget Sound region; (3) further taxonomic and size analysis of representative prey retained from previous processing of fish stomach contents; (4) quarterly sampling of nearshore demersal and neritic fishes along the eastern end of the Strait of Juan de Fuca (Burrows Bay to west Whidbey Island), for the purpose of collecting stomach samples representative of that area's nearshore fish communities; and (5) interviews with experts knowledgeable in the food habits of the region's marine invertebrates and fishes, seabirds and shorebirds, and marine mammals.

The overall objective was to formulate conceptual food web models which (1) documented the major species or taxa involved in carbon flow through the region's nearshore ecosystems; (2) illustrated regional, habitat, and seasonal variations in food web structure and energy flow, and (3) provided some semiquantitative evaluation of the quality (frequency of occurrence, etc.) and quantity (proportion of prey biomass transferred) of the food web linkages between prey and predators. The food web models were then summarized as to their complexity (i.e., number of species or taxa nodes; and number of primary, secondary, tertiary, and incidental linkages between nodes) according to trophic compartments (i.e., detritus processors, herbivores, planktivores, benthivores, and omnivores) and compared according to the objectives described at the end of Introduction.

Two steps were required in formulating the food web structures: (1) Definition of the principal species--from planktonic and macrophytic algae to marine mammals--composing the region's biotic communities, and (2) synthesis of predator-prey data on these organisms.

IV-A. Community Organization

Definition of the component species varied according to the diversity of organisms and the extent of quantitative data on their seasonal abundance and distribution. Because of the scattered and often meager survey data for marine birds and mammals, only subjective and often conjectural definitions of their community composition were possible. On the other hand, the data base for the region's marine benthic invertebrates has become voluminous, and unfortunately has not been subjected to any detailed analyses such as recurrent group analysis (Fager 1957) or numerical classification (Clifford and Stephenson 1975; Smith 1976). In these three cases, therefore, all raw data and relative indices of frequency of occurrence and abundance have been treated subjectively to provide the community descriptions.

The extensive, uniform data base for nearshore fishes provided by the DOE studies in north Puget Sound (Miller, et al., 1977) and the NOAA/MESA investigations in the Strait of Juan de Fuca (Simenstad, et al., 1977;

Cross, et al., 1978), however, was adequate for such analysis. Distributional analysis of many of these data was already in process by Wingert (unpubl. Ph.D. Thesis, Univ. Washington), who has applied hierarchical numerical classification techniques to the beach seine and townet data. This technique was further applied to the SCUBA transect data gathered in the rocky/kelp bed habitat by Moulton (1977) as a part of the DOE studies and to the littoral fish collections provided by the NOAA/MESA program (Cross, et al., 1978). While this scheme cannot be validly applied to the combined data sets as a whole, it can differentiate species groups or spatial patterns within the data subsets described by the different collection techniques. Thus, distinct species groups have been identified within the neritic environment sampled by the townet, shallow sublittoral habitats sampled by beach seine and SCUBA transect methods, and the littoral zone as sampled by using fish-specific narcotics.

The classification analysis utilized was of the agglomerative-polythetic variety,* applied to numerical fish catch data by species. Although the addition of life history stage designations was desirable, it was felt that the food habits data could not be meaningfully divided into that many subsets. Before calculation of inter-entity distances,* the data were scaled using a square-root transformation. Both normal or site classification and inverse classification were used, normal analysis for indication of species-site associations and inverse analysis for interspecific associations. The data matrix was further standardized using a species mean standardization,

$$Xij/\frac{1}{nz}\sum_{k=t}^{nst}$$

(where nz = number of non-zero elements in row i) for normal analysis and a species maximum standardization, Xij/Xmax (where Xmax = largest element in row i) for inverse analysis. A flexible fusion strategy (adjusted mean of Dhi and Dhj: $Dhk = \alpha Dhi + \alpha Dhj + \beta Dij$ where $\alpha = 1/2(1-\beta)$ and β was set at -0.25) (Lance and Williams 1967) was utilized for the process of clustering entities and groups of entities together.

Wingert's classification analyses were performed using the Ecological Analysis Package (EAP, R.W. Smith, Allan Hancock Foundation) system which was installed at the University of Southern California's IBM computer. The analyses of Moulton's (1977) SCUBA transect data and the MESA tidepool fish collections (Cross, et al., 1978) were made utilizing program CLUSTER, an interactive clustering program developed at Oregon State University and adapted to the University of Washington's CDC 6400 computer.

IV-B. Documentation and Quantification of Food Web Linkages

As the quality of data available for different trophic levels is usually unequal, an analysis of the structure and functional feeding relationships linking identifiable communities of organisms was considered more appropriate than, say, a bioenergetic analysis, even though the ultimate documentation of food web dynamics requires quantification of the transfer rates, efficiencies, and partitioning of carbon from primary producers through tertiary carnivores.

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*See Clifford and Stephenson (1975) and Smith (1976) for explanation of these approaches to numerical classification.

The process of energy acquisition by marine organisms can be characterized by three quantitative parameters which reflect both the trophic contribution by the prey organism to the predator and the energy expended by the predator to capture and consume the prey. These parameters are (1) the frequency of occurrence of each prey organism or functional prey group in the predator's diet, and (2) the percentage of the total number and (3) the percentage of the total ingested biomass contributed by each prey. Together they are important indicators of both the trophic (energy gained) and the behavioral (energy expended) processes which characterize predation. The simultaneous measurement of these three variables provides the most practical measurement of importance of food web linkages. As is described later in the section on modeling energy flow in marine ecosystems, all three variables are necessary to predictably quantify transfer rates between food web nodes.

It is characteristically uncommon, however, to find quantitative food habits or predation data in the literature which include all three variables. Often it is impossible to obtain all three, especially when it is desirable or necessary to obtain the data by observation or without killing the predator. Even if it is possible to obtain the stomach contents intact, the food items may be unidentifiable because of digestion, or uncountable (e.g., algae consumed by grazers), or of questionable trophic importance (e.g., rocks, bivalve shells, algae, matchsticks). Any biologist who has examined the stomach contents of marine predators will attest to the difficulty of explaining the significance of many food items, and how and why the predators consume them.

The optimal approach is a bioenergetic one including measurements of the caloric content of each food group, the assimilation efficiencies associated with each, and the energy expended to obtain them. Applications of the bioenergetic approach on the scale of a food web are rare, however.

When all three variables characterizing food web linkages were available, as in the DOE- and MESA-supported fish stomach analysis, they were combined into an Index of Relative Importance (I.R.I.) after Pinkas, et al. (1971), and Cailliet (1977). This index arbitrarily attaches equal weighting to the three variables and is expressed as the area occupied by each prey group plotted on a three-axis graph (see following section describing IRI in detail).

Previous species accounts of marine mammal food habits and feeding behavior are usually not detailed enough to generate quantitative representations of a species' trophic link to its prey species. In many cases the probable prey spectrum required inference from data sources originating outside the area of interest, such as the outer coasts of Washington and British Columbia and the Gulf of Alaska, but there is always an implied error associated with the different prey assemblages characterizing these regions. In these instances, Puget Sound organisms which are functionally equivalent to the recorded prey in another region are considered probable prey organisms.

IV-C. Stomach Analyses

Whole specimens or intact stomach samples of economically important fishes retained from the west Whidbey Island - Burrows Bay collections were examined according to a systematic, standard procedure (Terry 1977) which identifies the numerical and gravimetric composition of prey organisms, the stage of digestion of the contents, and the degree of stomach fullness. In the laboratory, the stomach samples were removed from the preservative (10% buffered formalin), or from the preserved whole fish, and soaked in cold water for at least two or three hours before examination. The stomach was then identified according to information on the label and then processed. Processing involved taking a total (damp) weight to nearest 0.1 g, and removing the contents from the stomach and weighing the empty stomach to obtain the total stomach contents weight by subtraction. Subjective numerical evaluations of the stomach condition or degree of fullness--scaled from 1 (empty) to 7 (distended)--and stage of digestion--scaled from 1 (all digested) to 5 (no digestion)--were made at this time. The stomach contents were then sorted and identified as far as was practicable, and the sorted organisms were counted and a total (damp) weight of each taxon obtained to nearest 0.001 g. If a sorted taxon was represented by too many individuals to count, the number was estimated using a random grid-counting procedure.

IV-D. Index of Relative Importance (IRI)

When possible, the relative importance of food web linkages has been represented as the percentage of the total IRI contributing to the total prey spectrum of a predator. Though this was possible for most of the nearshore fish data, insufficient data prevented an IRI assessment of the other biological groups. In these cases, the percentage of total biomass was considered the most important measure of trophic importance; the percentage of total prey abundance was considered second in the absence of biomass data; frequency of occurrence data were considered only in the absence of the other two measures. If two measures were given they were both considered.

The three-axis IRI graph (Fig. 1) illustrates frequency of occurrence (the proportion of stomachs containing a specific prey organism) plotted sequentially on the horizontal axis. Percentage of total abundance (number of prey) is plotted above the horizontal axis. Percentage of total weight of prey is plotted below the horizontal axis. All prey groups, including those which had to be assigned to a broad taxonomic level (family, order, class), have been arranged from left to right by decreasing frequency of occurrence. Prey taxa in differing stages of digestion (e.g., partly digested shrimp, "Natantia unidentified," as opposed to family, "Pandalidae," or species, "*Pandalus borealis*") were graphed separately.

The IRI value was computed as follows:

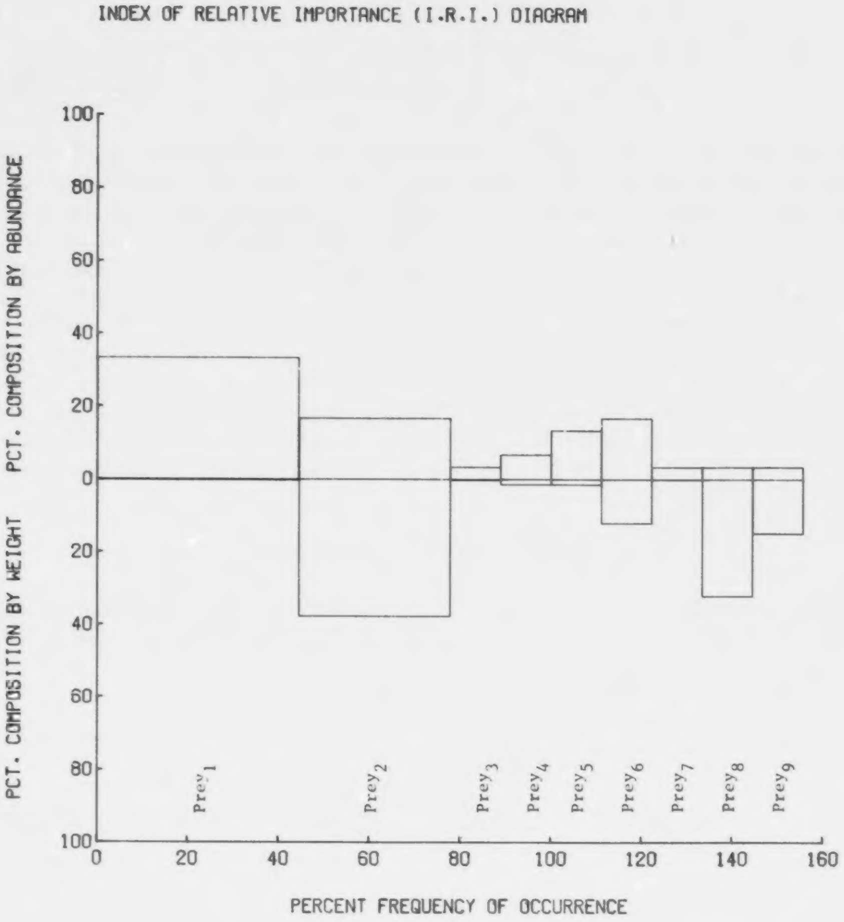

Fig. 1. Example of Index of Relative Importance (IRI) diagram.

Table 1. Example computation of IRI values and percentages of total IRI from data illustrated in Fig. 1.

Prey category	% Freq. of occurrence	% Numerical composition	% Gravimetric composition	Prey IRI	% Total IRI
1	44.44	33.33	0.21	1490.8	32.78
2	33.33	16.67	37.71	1812.5	39.85
3	11.11	3.33	0.17	38.9	0.86
4	11.11	6.67	1.43	90.0	1.98
5	11.11	13.33	1.37	163.4	3.59
6	11.11	16.67	12.07	319.3	7.02
7	11.11	3.33	0.06	37.7	0.83
8	11.11	3.33	32.14	394.1	8.66
9	11.11	3.33	14.85	202.0	4.44

$$\text{IRI} = \%\ \text{Frequency of occurrence}_i \left[\%\ \text{Numerical composition}_i + \%\ \text{Gravimetric composition}_i \right]$$

and is equivalent to the area encompassed by the bar for each prey category i composing the IRI diagrams. In order to compare the IRI values between prey spectra with different sample sizes, the overall importance of general prey taxa (e.g., all shrimp added together, including "Natantia unidentified" and those identified to family and species) has been discussed as a percentage of the summed total IRI values for individual spectra. Table 1 is an example of the IRI values and percentages of total IRI generated from the data diagrammed in Fig. 1. The advantage of the IRI value is that the more representative prey are not dominated by numerically rare but high biomass prey (e.g., prey_8, Fig. 1), by infrequently occurring but abundant or high biomass (when eaten) taxa, or by numerically abundant or frequently occurring taxa which contribute little in the way of biomass (e.g., prey_1, Fig. 1).

IV-E. Trophic Diversity

Three quantitative indices of the numerical and biomass composition of predator diets are used to describe trophic diversity (see Pielou 1975):

(1) Percent dominance index:

$$\%\ \text{Dominance} = \Sigma(p_i)^2$$

where p_i's are ratios of the number or biomass of prey i to the total prey abundance or biomass.

(2) Shannon-Wiener diversity index:

$$H' = -\sum_{i=1}^{s} (p_i \ln_2 p_i)$$

where p_i's are the same as above.

(3) Evenness index:

$$e = \overline{H}/\ln S$$

where $\overline{H}$ = mean H, S= number of species, and lns= Hmax.

IV-F. Sources of Food Web and Community Data

The amount of quantitative data on nearshore marine community structure in north Puget Sound and the Strait of Juan de Fuca has been greatly increased by DOE and NOAA/MESA baseline studies. Quantitative food web data are generally restricted to fishes, however. Trophic data for the remaining taxa usually are for other temperate ocean regions or for related species.

The following sources have provided the data base for the region.

	Data existing for north Puget Sound and Strait of Juan de Fuca*	Unpublished data and sources of expertise**
Algae (Qualitative)	DOE and MESA baseline studies (Nyblade 1977,1978; Webber 1977,1979); other Puget Sound studies	T. Mumford, DNR C. Nyblade, UW R. Thom, UW
Invertebrates (Semi-quantitative)	DOE and MESA baseline studies (Nyblade 1977,1978; Webber 1977,1979)	C. Nyblade, UW B. Webber, WWU
Fishes (Quantitative)	DOE and MESA baseline studies (Miller, et al., 1977; Simenstad, et al., 1977; Cross, et al., 1978; Moulton 1977); other Puget Sound studies (Simenstad and Kinney 1978; Fresh, et al., 1978; Fresh 1979)	B. Miller, UW C. Simenstad, UW J. Cross, UW S. Borton, Seattle Aquarium
Seabirds and shorebirds (Semi-quantitative)	Natl. Wildl. Fed. study (Manuwal 1977); other studies (Richardson 1961; Wilson 1977; Hartwick 1973; Salo 1975)	D. Manuwal, UW S. Spiech, UW B. Jeffries, Wn. Dept. Game R. Parker, Wn. Dept. Game T. Wahl, Bellingham
Marine mammals (Qualitative)	MESA baseline studies (Everitt, et al., in press; Bigg 1969; Manzer and Cowan 1956; Pike and MacAskie 1969; Scheffer and Sperry 1931; Scheffer and Slipp 1948)	S. Rice, NMFS-MML C. Fiscus, NMFS-MML B. Everitt, NMFS-MML T. Newby, NMFS-MML K. Balcomb, Orca Survey R. Osborne, Orca Survey M. Bigg, Dept. Environ. Can.

IV-G. Definitions

The following definitions are of terms and abbreviations used in this report.

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*See pertinent appendices for references associated with each biotic group.

**DNR = Washington Department of Natural Resources
UW = University of Washington
WWU = Western Washington University
NMFS-MML = National Marine Fisheries Service, Marine Mammal Laboratory

Assemblage: A restricted group of taxa or organisms which are found together.

Autotrophic: Self-nourishing; denoting those organisms capable of constructing organic matter from inorganic matter.

Benthivore: Organism which feeds on benthic organisms.

Carnivore: Organism which feeds on other organisms.

Community: The aggregation of organisms, plants and animals, within a specified area which are interrelated in some manner.

Consumers: Heterotrophic organisms, chiefly animals, which ingest other organisms or particulate organic matter.

Demersal: Living on or near the bottom.

Deposit feeder: Organism, typically benthic, which is either somewhat selective or almost completely unselective in feeding; includes organisms which sweep the surface or use ciliary tracts along extensile tentacles.

Detritivore: Organism which utilizes detritus and/or its associated microflora for food.

Detritus: Finely divided sinkable material of organic or inorganic origin which is suspended in the water.

DOE: Washington State Department of Ecology.

Entrapment carnivore: Organism which, by using tentacles or mucous webs, entraps other organisms.

Epibenthic: Associated primarily with the surface of the bottom but also with the water column directly above the bottom.

Facultative feeder: An organism which is not constrained to feeding on one general type of plant or animal but may feed on organisms from several trophic levels.

Filter feeder: Carnivore which feeds by engulfing large numbers of prey organisms as they swim through the water. The filtering apparatus (such as gill rakers) retains the prey but lets the water pass out of the mouth.

Food web: The network of organisms, each of which provides food to one or more organisms in the same or higher trophic level.

Food web linkage: The trophic connection between food web nodes.

Food web node: Species, taxon, or functional feeding group constituting a unique prey or predator compartment in a food web.

Habitat: The total of environmental conditions of a specific place that is occupied by an organism, a population, or a community.

Herbivore: Organism which feeds on plant material.

Heterotrophic: Dependent on organic matter for food.

IRI: Index of Relative Importance (see Section IV-D).

Littoral zone: The zone between the high and low water marks--i.e., the intertidal zone.

MESA: NOAA's Marine Ecosystem Analysis Program.

Neritic zone: Shallow surface water zone extending from the high-tide mark to the edge of the continental shelf. Neuston nets, surface trawls, and townets were assumed to sample neritic organisms.

Obligate feeder: Organism constrained by morphology or behavior to feeding on one general type of plant or animal.

Omnivore: Organism which feeds on both plant and animal matter.

Pelagic: Inhabiting the water column.

Planktivore: Organism which feeds on suspended microorganisms.

Raptoral carnivore: Organism which pursues and individually captures its prey.

Sublittoral zone: The benthic zone extending from mean low water (the seaward limit of the littoral zone) to 200 m, or the edge of the continental shelf usually defined as being 200 m deep. Beach seines were assumed to sample the shallow sublittoral, just below the littoral zone.

Suspension feeder: Typically a benthic organism which processes the water flowing over the substrate, feeding on diatoms and other microscopic organisms and suspended detritus.

Trophic level: A group of organisms in a food web that secures food in the same general manner.

IV-H. Place Names and Locations and Associated Habitats

Locations of DOE and MESA sampling sites, and their representative habitat types, which are cited in this report are indicated in Fig. 2.

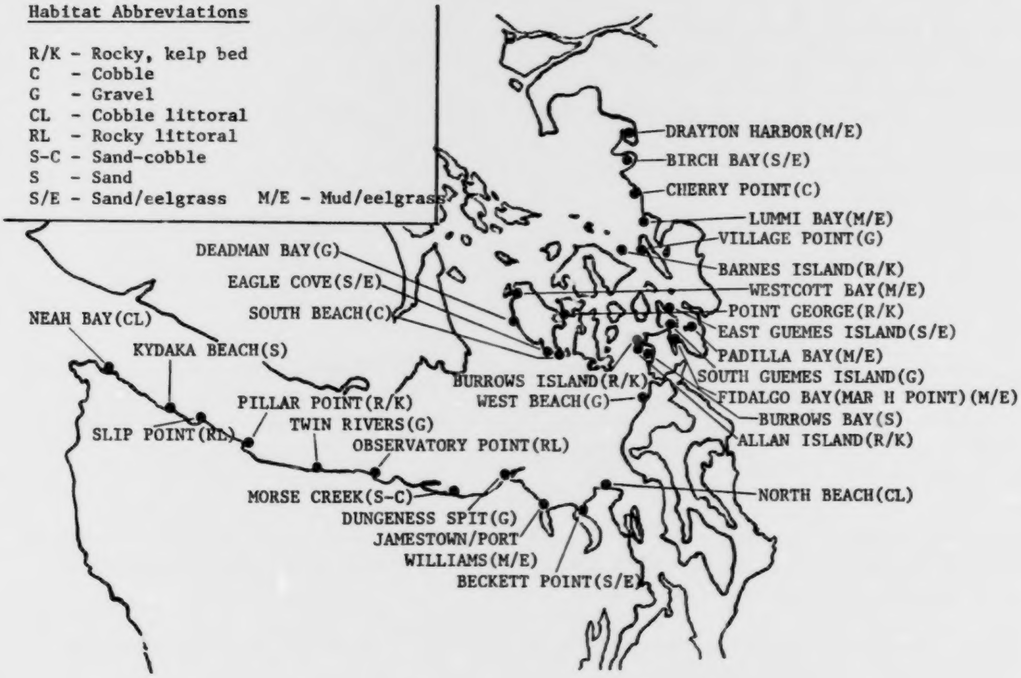

Habitat Abbreviations
R/K - Rocky, kelp bed
C - Cobble
G - Gravel
CL - Cobble littoral
RL - Rocky littoral
S-C - Sand-cobble
S - Sand
S/E - Sand/eelgrass
M/E - Mud/eelgrass
DRAYTON HARBOR(M/E)
BIRCH BAY(S/E)
CHERRY POINT(C)
LUMMI BAY(M/E)
VILLAGE POINT(G)
DEADMAN BAY(G)
BARNES ISLAND(R/K)
EAGLE COVE(S/E)
WESTCOTT BAY(M/E)
SOUTH BEACH(C)
POINT GEORGE(R/K)
NEAH BAY(CL)
EAST GUEMES ISLAND(S/E)
KYDAKA BEACH(S)
PADILLA BAY(M/E)
BURROWS ISLAND(R/K)
SOUTH GUEMES ISLAND(G)
PILLAR POINT(R/K)
WEST BEACH(G)
FIDALGO BAY(MAR H POINT)(M/E)
TWIN RIVERS(G)
BURROWS BAY(S)
SLIP POINT(RL)
OBSERVATORY POINT(RL)
ALLAN ISLAND(R/K)
MORSE CREEK(S-C)
NORTH BEACH(CL)
DUNGENESS SPIT(G)
JAMESTOWN/PORT WILLIAMS(M/E)
BECKETT POINT(S/E)

Fig. 2. Locations of DOE and MESA sampling sites from which nearshore community and food web data were obtained.

V. Results and Discussion

V-A. Food Web Structure of Northern Puget Sound and the Strait of Juan de Fuca

Synopses of the principal nearshore communities and the prey spectra of the prominent species are in Appendix A for algae and invertebrates, Appendix B for fishes, Appendix C for seabirds and shorebirds, and Appendix D for marine mammals. The results of the stomach analyses conducted specifically for this report are in Appendix B, and the results of the nearshore fish sampling along the western shoreline of Whidbey Island and at Burrows Bay have been presented in Cross, et al. (1978), and Miller, et al. (in press).

Composite food webs have been constructed for seven representative nearshore habitats characterizing north Puget Sound and the Strait of Juan de Fuca--neritic, rocky/kelp bed sublittoral, rocky littoral, cobble littoral, and shallow sublittoral zones of gravel-cobble, sand-gravel/eelgrass, and mud/eelgrass habitats. These composite webs are illustrated as being much more complex than they actually are at any one time because both energy sources and consumers change seasonally and vary according to differences in the location's environmental character (e.g., wave exposure, sediment sources, freshwater influences). Accordingly, the food webs were constructed by season and individual location where data on community structure existed. These structures have been summarized in tables describing the distribution and abundance of food web nodes among functional trophic groups and the number and relative importance of food web linkages between trophic levels (Appendix E). The following discussion is based on, and constrained by, these simple representations of very complex, dynamic "structures."

V-A - 1 Neritic Food Webs

Neritic food webs, i.e., those of the surface waters and water column in the nearshore region, are the only webs based principally on autotrophic production (Fig. 3) and are the least complex (least number of linkages per node, 1.76) although the cobble littoral food web exhibits a slightly less diverse structure (Tables 2 and 3). Phytoplankton (chrysophytes, diatoms, dinoflagellates, microflagellates) produce organic carbon which is grazed by pelagic zooplankton, principally through suspension feeding. These small animals may in turn be utilized by larger zooplankton such as primary carnivores. Although plankton studies in the Strait of Juan de Fuca and north Puget Sound have been restricted to offshore waters, Chester, et al. (1977), suggested that diatoms (*Skeletonema costatum*, *Thalassiosira* sp., *Chaetoceros* sp.) are the principal components of the plankton blooms and various microflagellate species form the dominant non-bloom component of the community. Among the herbivores, small calanoid copepods (*Pseudocalanus* sp., *Acartia longiremis*, *Microcalanus* sp., *Oncaea borealis*) and the cyclopoid copepod *Oithona similis* numerically dominate the surface water zooplankton community. Larger calanoids *Calanus plumchrus* and *C. marshallae* migrate into the surface layers from deeper water at night (Parsons, et al., 1969; Chester, et al., 1977). Larger

Table 2. Distribution and abundance of food web nodes for food webs characterizing nearshore habitats of north Puget Sound and the Strait of Juan de Fuca.

		Herbivores						Planktivores			Benthivores			Piscivores				
Habitat	Detritus processor	Vascular plants	Suspension feeders	Microalgae grazers	Macroalgae grazers	Mixed algae/ detritus	Omnivores	Raptoral carnivores	Entrapment carnivores	Filter feeders	Deposit feeders	Suspension feeders	Carnivores	Pelagic	Demersal	Terrestrial origin	Non-feeding	Total # of nodes N_n
Neritic	2		5			1		12	1	3				6		1	7	38
Rocky sublittoral w/kelp beds	6		2	1	1	2	3	14	1			1	11	5	1			48
Rocky littoral	7		3	3	2	2		10				1	13		5			46
Cobble littoral	5		3	2	1	2	1	4	1			1	12		3			35
Gravel-cobble shallow sublittoral	6		2			4	5	10				1	11		2			41
Sand/eelgrass shallow sublittoral	5	4		1		4	4	9					13					40
Mud/eelgrass shallow sublittoral	4	4	2	1	1	2	9	10			1		11		1			46

Table 3. Number and relative importance of food web linkages to trophic levels characterizing nearshore habitats of northern Puget Sound and the Strait of Juan de Fuca. 1° = primary, 2° = secondary, 3° = tertiary, Incid. = incidental trophic linkages.

Habitat	Detritus grazers				Phytoplankton & microalgae grazers				Macroalgae & vascular plant grazers				Mixed food consumers				Primary carnivores				Secondary carnivores				Tertiary carnivores				Subtotal				Total # linkages N_1	$\bar{x}$ No. linkages per node (N_1/Nn)
	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid		
Neritic	2				5										2		1		4		4	3	13	9	2	2	4	16	14	5	23	25	67	1.76
Rocky sublittoral w/kelp beds	5				4.								1	2	11	2	3	1	6	6	5	2	11	31	2	2	3	7	12	6	26	26	104	2.17
Rocky littoral	7				5	1			2	1		1		2	2		2	1	4	16	5	3	13	9			25	2	21	8	45	27	101	2.20
Cobble littoral	5				4				1					2	4		1			2	1	3	11	16			15	9	12	5	30	27	74	2.11
Gravel-cobble shallow sublittoral	6				3									4	9	5	2			4	8	6	17	15				12	19	10	26	36	91	2.22
Sand/eelgrass shallow sublittoral	4				1				4					5	13	7			2	2	3	3	37	13					12	8	52	22	94	2.35
Mud/eelgrass shallow sublittoral	4				3				5					4	25	4		3	2	2	4	4	18	32			2	2	16	11	47	40	114	2.48

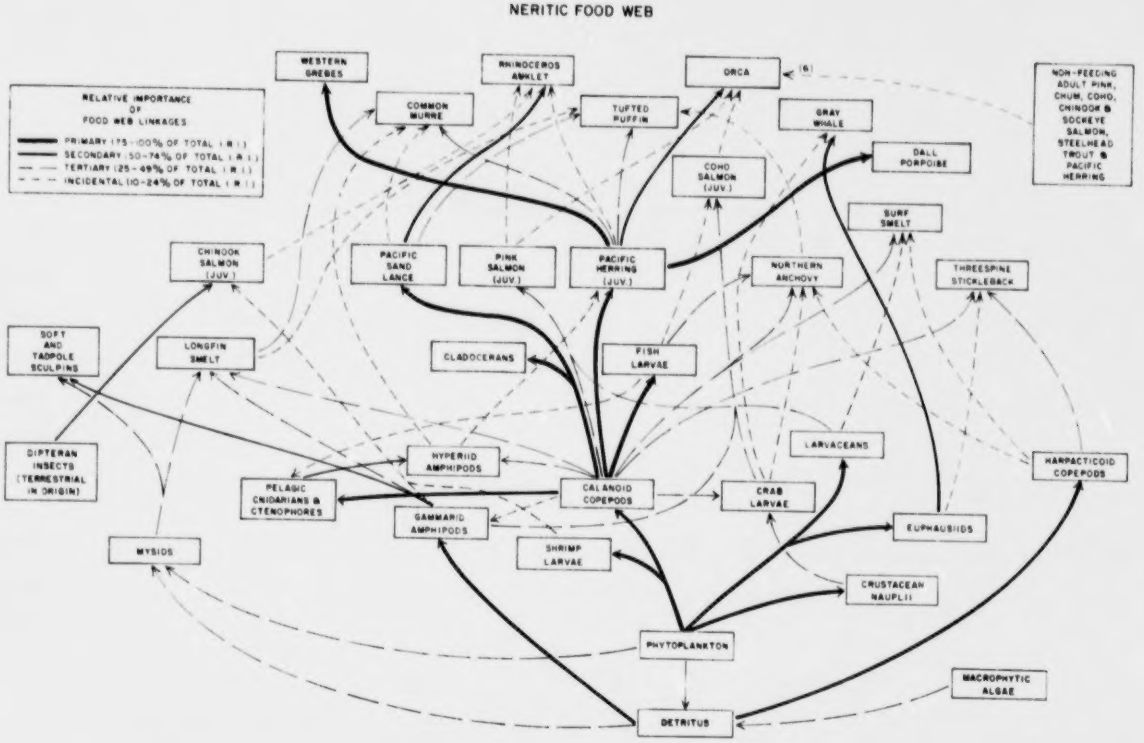

NERITIC FOOD WEB
RELATIVE IMPORTANCE OF FOOD WEB LINKAGES
PRIMARY (75-100% OF TOTAL I.R.I.)
SECONDARY (50-74% OF TOTAL I.R.I.)
TERTIARY (25-49% OF TOTAL I.R.I.)
INCIDENTAL (10-24% OF TOTAL I.R.I.)
WESTERN GREBES
COMMON MURRE
RHINOCEROS AUKLET
TUFTED PUFFIN
ORCA
(6)
GRAY WHALE
DALL PORPOISE
NON-FEEDING ADULT PINK, CHUM, COHO, CHINOOK & SOCKEYE SALMON, STEELHEAD TROUT & PACIFIC HERRING
COHO SALMON (JUV.)
SURF SMELT
CHINOOK SALMON (JUV.)
PACIFIC SAND LANCE
PINK SALMON (JUV.)
PACIFIC HERRING (JUV.)
NORTHERN ANCHOVY
THREESPINE STICKLEBACK
SOFT AND TADPOLE SCULPINS
LONGFIN SMELT
CLADOCERANS
FISH LARVAE
LARVACEANS
HARPACTICOID COPEPODS
DIPTERAN INSECTS (TERRESTRIAL IN ORIGIN)
HYPERIID AMPHIPODS
PELAGIC CNIDARIANS & CTENOPHORES
CALANOID COPEPODS
CRAB LARVAE
GAMMARID AMPHIPODS
EUPHAUSIIDS
MYSIDS
SHRIMP LARVAE
CRUSTACEAN NAUPLII
PHYTOPLANKTON
MACROPHYTIC ALGAE
DETRITUS

Fig. 3. Composite food web characteristic of neritic habitats in northern Puget Sound and the Strait of Juan de Fuca.

grazers include euphausiids (*Euphausia pacifica*, *Thysanoessa longipes*, *T. spinifera*), larvaceans (*Oikopleura dioica*), and larval and juvenile stages of other crustaceans.

Carnivorous zooplankton includes cnidarian (Hydromedusae, scyphozoans), ctenophores (*Beroe* sp., *Pleurobranchia* sp.), hyperiid amphipods (*Parathemisto pacifica*, *Hyperoche medusarum*), larvae of large benthic crustaceans (brachyuran crabs), and chaetognaths (*Sagitta elegans*, *S. lyra*).

The principal secondary consumers are neritic schooling fishes such as juvenile Pacific herring, Pacific sand lance, northern anchovy, longfin smelt, and surf smelt. Some of these species are present in the community for only a part of their life history, as in the case of herring which occupy the neritic waters of the region for their first year before entering the North Pacific Ocean. Some species such as Pacific sand lance are present in the community from larvae to adults. Other species are even more transient though ecologically important during their short residency--for example, juvenile salmonids which occupy neritic waters for two weeks to six months during their migrations out of Puget Sound and the Strait of Georgia. Several species, including coho salmon, may spend their whole life cycle in the region's inland waters, changing trophic levels several times.

Almost all the marine birds and mammals occupy positions of tertiary carnivores. Only the gray whale, which may enter the region during its oceanic migration, can be considered a secondary consumer by its utilization of zooplankton (euphausiids and crab larvae). The high production of calanoid copepods, which are eaten by neritic fishes, is undoubtedly responsible for maintaining large numbers of tertiary consumers and their diversity. For example, the various alcid seabirds seem to have evolved their reproductive period and nesting location in conjunction with the peak occurrence of larval and juvenile neritic fishes. The Protection Island colonies appear to be very dependent on the fluxes of neritic fishes occupying the region and juvenile salmonids migrating through it.

The diversity in nodes and linkages of the various neritic food webs also reflects the importance of spawning regions of the adult fishes. In general the regions around Cherry Point, Anacortes, and the San Juan Islands, which are in proximity to spawning areas of Pacific herring, tended to exhibit more complex food webs than western Whidbey Island and the Strait of Juan de Fuca (Appendix Tables E-1, E-2). This also reflects the role of contained embayments in providing nursery and rearing area for the larvae of neritic fishes, regardless of whether or not these embayments were significant spawning areas (Fresh 1979). Thus, north Puget Sound with its abundant embayments (Birch Bay, Padilla Bay, Fidalgo Bay, Westcott Bay, Lopez Sound) tends to have more highly developed neritic food webs than the eastern Strait of Juan de Fuca, which has only two embayments (Discovery Bay and Sequim Bay), and the western strait which has no embayments.

There are several neritic fishes (e.g., surf smelt and longfin smelt) which utilize sand-gravel beaches for spawning. The abundance of this habitat along the Strait of Juan de Fuca obviously contributes to the neritic food webs of that region more than in north Puget Sound.

Seasonal variations in the neritic food webs are probably the most pronounced of any of the habitats examined (Appendix Tables E-1, E-2). This would appear to be the result of the extreme seasonality of the primary production cycle in the temperate waters at these latitudes. Accompanying this effect is the reproductive cycle of most of the neritic fishes, which produce larvae at the time of maximum availability of appropriate food organisms. Despite the decline in many lower trophic level organisms, the overall diversity (number of nodes) of the fall and winter food webs is maintained by seabirds wintering in the protected inland waters of the region.

V-A - 2 Rocky Sublittoral Food Webs

Rocky sublittoral habitats of the region and their associated kelp bed (*Nereocystis*, *Macrocystis*) community showed a mixture of neritic and sublittoral food webs (Fig. 4) and thus the highest number of food web nodes of any habitat and the second highest number of linkages (Tables 2, 3). This in part reflects the steep gradient, well flushed character of this habitat, which makes neritic organisms available for use by kelp bed carnivores. This is evident in the number of secondary carnivores which occupy the kelp bed habitat, for protection from predation or some other non-food-oriented purpose, but which typically feed upon neritic organisms. Black, quillback, and yellowtail rockfish, juvenile gadids and rockfish, Heermann's gulls, and Brandt's cormorants prey on food resources characteristic of the neritic communities. A completely different food web is organized around the production of macrophytic algae and the accumulation of detritus. These carbon sources are in turn utilized by epibenthic zooplankton and benthic organisms which are prey for epibenthic- and benthic-feeding carnivores. Although the bottom habitat is not as capable of supporting large numbers of infaunal species as the soft-sediment environments, epibenthic shrimps, crabs, mysids, gammarid amphipods, isopods, and copepods occupy the microhabitat provided by the kelp holdfasts and the macroalgae understory. Important shrimp species include *Spirontocaris prionata*, *Crangon stylirostris*, *C. franciscorum*, and *Heptacarpus stimpsoni*. Crabs include *Cancer gracilis*, *C. oregonensis*, *Oregonia gracilis*, *Scyra acutifrons*, *Hyas lyratus*, *Pagurus beringanus*, *P. dalli*, *P. hirsutiusculus*, *Petrolistes eriomerus*, *Loxorhynchus erispatus*, and *Pachycheles* sp. Mysids include *Holmesiella anomala*, *Neomysis awatschensis*, and *Archaeomysis grebnitski*. Gammarids include *Eusiroides* sp., *Hyale frequens*, *Parapleustes pugettensis*, *Erichtonius brasiliensis*, *Photis* sp., *Amphithoe simulans*, and *A. lacertosa*. Isopods include *Exosphaeroma amplicauda*, *E. media*, *Gnorimosphaeroma oregonense*, and *Dynamenella sheareri* (Nyblade 1977, 1978; Leaman 1976).

Secondary carnivores which utilize these epibenthic organisms are all demersal or bottom-oriented fishes, including kelp greenling, copper rockfish, cabezon, longfin sculpin, striped seaperch, lingcod, scalyhead sculpin, red Irish lord, and blackeye goby. Although the data base for the prey composition of tertiary carnivores, marine mammals, is inadequate, it appears from existing information that harbor seals prey on smaller demersal fishes, northern sea lions on the neritic-feeding rockfish, and

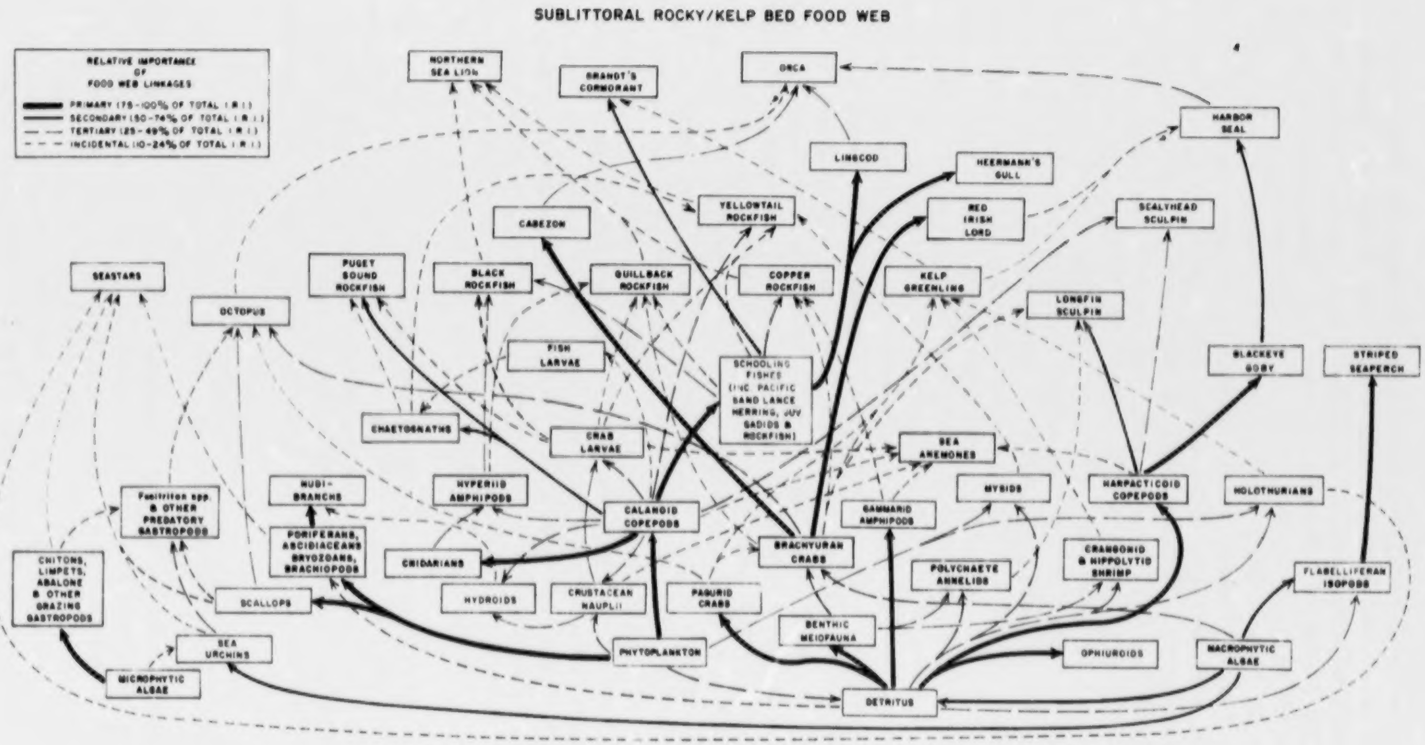

SUBLITTORAL ROCKY/KELP BED FOOD WEB
RELATIVE IMPORTANCE OF FOOD WEB LINKAGES
PRIMARY (75-100% OF TOTAL I.R.I.)
SECONDARY (50-74% OF TOTAL I.R.I.)
TERTIARY (25-49% OF TOTAL I.R.I.)
INCIDENTAL (10-24% OF TOTAL I.R.I.)
NORTHERN SEA LION
BRANDT'S CORMORANT
ORCA
HARBOR SEAL
LINGCOD
HEERMANN'S GULL
YELLOWTAIL ROCKFISH
CABEZON
RED IRISH LORD
SCALYHEAD SCULPIN
SEASTARS
OCTOPUS
PUGET SOUND ROCKFISH
BLACK ROCKFISH
QUILLBACK ROCKFISH
COPPER ROCKFISH
KELP GREENLING
LONGFIN SCULPIN
FISH LARVAE
SCHOOLING FISHES (INC PACIFIC SAND LANCE HERRING, JUV GADIDS & ROCKFISH)
BLACKEYE GOBY
STRIPED SEAPERCH
CHAETOGNATHS
CRAB LARVAE
SEA ANEMONES
Fusitriton spp. & OTHER PREDATORY GASTROPODS
NUDI-BRANCHS
HYPERIID AMPHIPODS
CALANOID COPEPODS
MYSIDS
HARPACTICOID COPEPODS
HOLOTHURIANS
GAMMARID AMPHIPODS
CHITONS, LIMPETS, ABALONE & OTHER GRAZING GASTROPODS
PORIFERANS, ASCIDIACEANS BRYOZOANS, BRACHIOPODS
CNIDARIANS
BRACHYURAN CRABS
POLYCHAETE ANNELIDS
CRANGONID & HIPPOLYTID SHRIMP
FLABELLIFERAN ISOPODS
SCALLOPS
HYDROIDS
CRUSTACEAN NAUPLII
PAGURID CRABS
BENTHIC MEIOFAUNA
SEA URCHINS
PHYTOPLANKTON
OPHIUROIDS
MACROPHYTIC ALGAE
MICROPHYTIC ALGAE
DETRITUS

Fig. 4. Composite food web characteristic of sublittoral rocky/kelp bed habitats in northern Puget Sound and the Strait of Juan de Fuca.

orcas on the large demersal fishes and harbor seals.

Comparison of the rocky/kelp bed communities and food webs in different regions of north Puget Sound and the Strait of Juan de Fuca is difficult because of the lack of a uniform data base. While the DOE baseline studies produced comparable data for three areas in north Puget Sound (Miller, et al., 1977; Moulton 1977), no such data exist for the Strait of Juan de Fuca. Only Leaman's (1976) studies of the kelp bed communities in Barkley Sound, outer Vancouver Island, contain quantitative data on species composition, abundance, and food habits, although only one season was represented. Examination of the food web structures of north Puget Sound (Appendix Tables E-3, E-4) indicated that there may not be significant differences between the different regions sampled and that seasonal variation is comparatively low. Moulton (1977) indicated that of the dominant species in the community, quillback rockfish, copper rockfish, and longfin sculpin tended to show strong seasonal fluctuations. The meager data from the strait indicate some significant differences in species composition, seasonality, and prey resources. Both Leaman's (1976) data and unpublished records from repeated SCUBA dives (J. Cross, FRI, UW) in the region suggest that both seaperch and rockfish may be more prevalent and that several of these species (striped seaperch, canary rockfish, and black rockfish) show strong seasonality. In addition, Leaman's stomach analysis data indicated that caprellid amphipods may provide more important prey resources for demersal fishes, especially red Irish lord, kelp greenling, and scalyhead sculpin, than documented for north Puget Sound. Assuming a predominantly detritivorous feeding mode for caprellids, these data suggest that detritus production may be higher on the exposed coast, perhaps because of the extensive *Macrocystis* kelp beds which occur there. (*Macrocystis* extends into the Strait of Juan de Fuca only as far as Crescent Bay.) Although such differences may be very real, Barkley Sound is not necessarily representative of the exposed coast and the Strait of Juan de Fuca, since high temperatures, high salinities, and low tidal mixing occur in Barkley Sound in summer (T. Mumford, Jr., Wn. Dept. Nat. Res.). Nonetheless, the importance of *Macrocystis* as a perennial habitat and source of detritus should be considered in evaluating the structures of the rocky/kelp bed community and food web in the Strait of Juan de Fuca.

The importance of the rocky/kelp bed habitat, and the lack of community or food web data, in the Strait of Juan de Fuca should not be ignored in the future. This habitat probably forms the largest proportion of shoreline west of Port Angeles, hence playing a major role in the production of macroalgae and detritus at the base of the food webs in all habitats of this region.

V-A-3 Rocky Littoral Food Webs

The invertebrate fauna of the littoral portion of the rocky/kelp bed habitat has been extensively studied throughout north Puget Sound (Kozloff 1973). The fish fauna has been only peripherally examined in north Puget Sound (Friday Harbor Laboratories, class reports), though sampled extensively in the Strait of Juan de Fuca as part of the MESA studies (Cross, et al., 1978). The information that does exist for the San Juan Islands (J. Cross, FRI) suggests that the community composition is similar to that documented for the strait, although there is unquantified evidence that the rocky littoral fish fauna in north Puget Sound is not as diverse or as abundant as along the Strait of Juan de Fuca. The eastern shoreline of north Puget Sound has very little rocky littoral. The food webs summarized in Fig. 5, Tables 2 and 3, and Appendix Tables E-5 and E-6 represent the two regions combined.

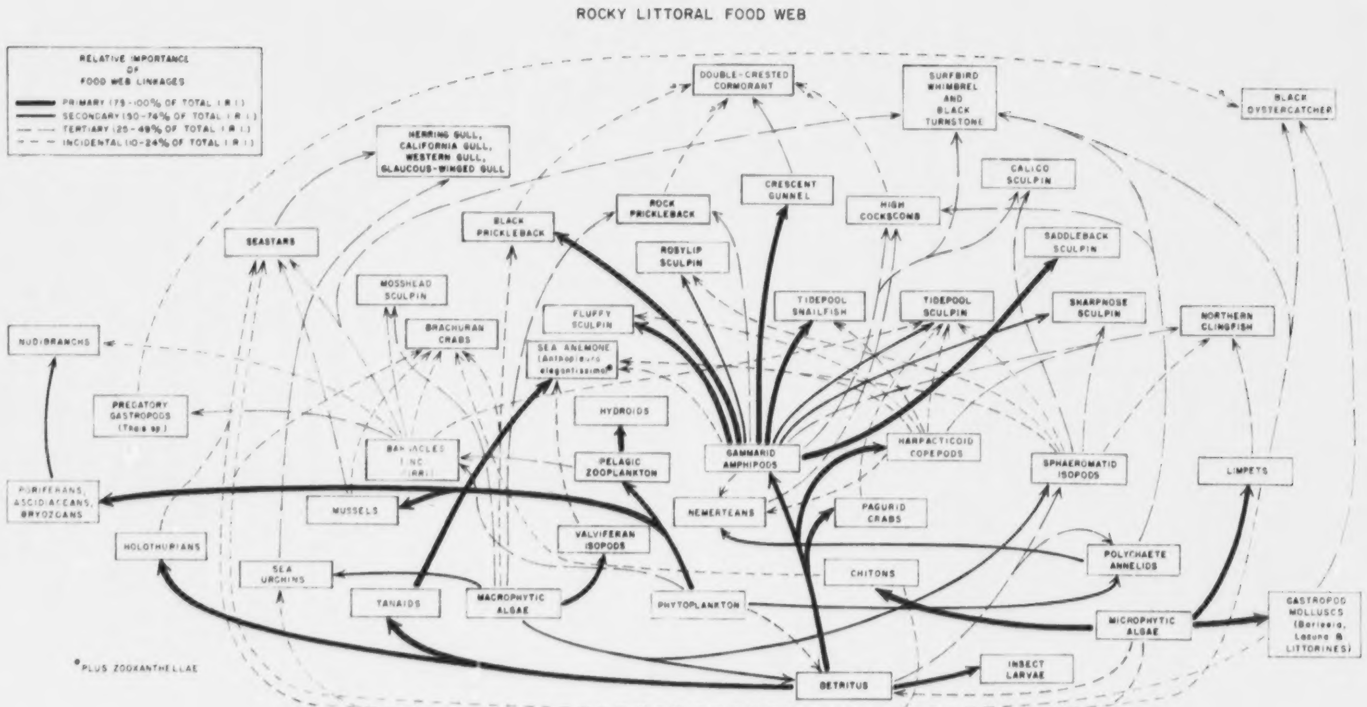
Detritivores and grazers form the basis of the food web leading to the secondary carnivores in the rocky littoral. Detritivorous gammarid amphipods are especially important, accounting for over half of the food web linkages to the secondary trophic level (Fig. 5). Although many of the amphipods may enter the littoral system with each tidal exchange, resident populations are probably sustained in the littoral habitats because of the protection and food supply provided by the extensive macroalgal community typical of this region (Carefoot 1977). Detritus production is sustained both by senescence of annual macroalgae and by the action of herbivores such as chitons, limpets, sea urchins, and snails which by their grazing release macroalgae from the substrate. The seastar _Pisaster ochraceus_ plays the "keystone" role in maintaining a diverse algal community by preferentially feeding on the space-dominating mussel _Mytilus_ sp. on the outer exposed coast (Paine 1974). Gastropods such as _Thais_ sp. and the seastars _Leptasterias_ sp. fill that role inside the Strait of Juan de Fuca. As pointed out by Paine's exclusion experiments, removal of a keystone species results in dramatic shifts in community dominance and diversity. Theoretically, removal of these carnivores would decrease macroalgae production in the rocky littoral and ultimately reduce the supply of detritus for this habitat and adjacent ones.

At the base of the food web seasonal fluctuations are quite prominent, especially those associated with the annual die-off of macroalgae and the massive recruitment of barnacles and mussels. Very little seasonal variation is evident among the principal food web relationships at the higher trophic levels, however (Appendix Tables E-5, E-6). Any variation can be attributed to the occurrence of less common fishes such as saddleback sculpin, fluffy sculpin, and sharpnose sculpin, and migratory shorebirds such as surfbird, whimbrel, and black turnstone.

V-A. 4 Cobble Littoral Food Webs

Compared with the rocky littoral, the cobble littoral is generally less diverse and less complex in its community and food web structure (Fig. 6; Tables 2,3), especially at the secondary carnivore (fishes) level. The principal components are typically the same species or functional groups, but food web nodes and linkages are three-quarters as numerous as in the cobble littoral. It is important to point out here that although the food web structure is less diverse or connected, the extensive beneath-rock habitat, combined with the rock benthic epifauna, may make this habitat one of the most productive on the basis of standing stock of the community and the extent of this habitat in the region.

Some striking differences in food web structure, as compared to the rocky littoral, include the increased importance of idoteid isopods (_Idotea urotoma_, _Pentidotea montereyensis_), the decreased importance of shorebirds, and the presence of the pigeon guillemot, a diving piscivore.



ROCKY LITTORAL FOOD WEB

RELATIVE IMPORTANCE
OF
FOOD WEB LINKAGES
PRIMARY (75-100% OF TOTAL I R I)
SECONDARY (50-74% OF TOTAL I R I)
TERTIARY (25-49% OF TOTAL I R I)
INCIDENTAL (10-24% OF TOTAL I R I)
DOUBLE-CRESTED CORMORANT
SURFBIRD WHIMBREL AND BLACK TURNSTONE
BLACK OYSTERCATCHER
HERRING GULL, CALIFORNIA GULL, WESTERN GULL, GLAUCOUS-WINGED GULL
CALICO SCULPIN
CRESCENT GUNNEL
HIGH COCKSCOMB
ROCK PRICKLEBACK
BLACK PRICKLEBACK
SEASTARS
ROSYLIP SCULPIN
SADDLEBACK SCULPIN
MOSSHEAD SCULPIN
TIDEPOOL SNAILFISH
TIDEPOOL SCULPIN
SHARPNOSE SCULPIN
NORTHERN CLINGFISH
FLUFFY SCULPIN
BRACHURAN CRABS
SEA ANEMONE (Anthopleura elegantissima)*
NUDIBRANCHS
HYDROIDS
PREDATORY GASTROPODS (Thais sp.)
BARNACLES (INC. CIRRI)
PELAGIC ZOOPLANKTON
GAMMARID AMPHIPODS
HARPACTICOID COPEPODS
SPHAEROMATID ISOPODS
LIMPETS
PORIFERANS, ASCIDIACEANS, BRYOZOANS
MUSSELS
NEMERTEANS
PAGURID CRABS
HOLOTHURIANS
VALVIFERAN ISOPODS
POLYCHAETE ANNELIDS
SEA URCHINS
CHITONS
TANAIDS
MACROPHYTIC ALGAE
PHYTOPLANKTON
MICROPHYTIC ALGAE
GASTROPOD MOLLUSCS (Barleeia, Lacuna & LITTORINES)
INSECT LARVAE
DETRITUS
*PLUS ZOOXANTHELLAE

Fig. 5. Composite food web characteristic of rocky littoral habitats in northern Puget Sound and the Strait of Juan de Fuca.

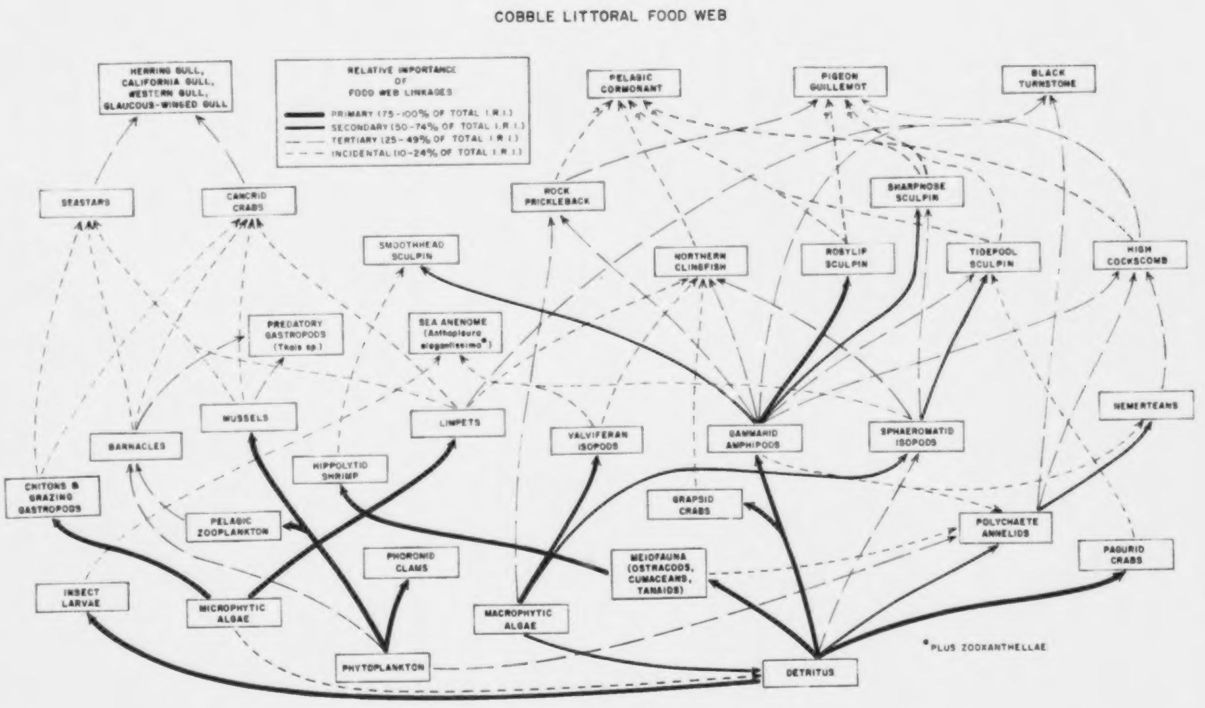

COBBLE LITTORAL FOOD WEB
HERRING GULL, CALIFORNIA GULL, WESTERN GULL, GLAUCOUS-WINGED GULL
RELATIVE IMPORTANCE OF FOOD WEB LINKAGES
PRIMARY (75-100% OF TOTAL I.R.I.)
SECONDARY (50-74% OF TOTAL I.R.I.)
TERTIARY (25-49% OF TOTAL I.R.I.)
INCIDENTAL (10-24% OF TOTAL I.R.I.)
PELAGIC CORMONANT
PIGEON GUILLEMOT
BLACK TURNSTONE
SEASTARS
CANCRID CRABS
ROCK PRICKLEBACK
SHARPNOSE SCULPIN
SMOOTHHEAD SCULPIN
NORTHERN CLINGFISH
ROSYLIP SCULPIN
TIDEPOOL SCULPIN
HIGH COCKSCOMB
PREDATORY GASTROPODS (Thais sp.)
SEA ANENOME (Anthopleura elegantissima*)
NEMERTEANS
MUSSELS
LIMPETS
BARNACLES
VALVIFERAN ISOPODS
GAMMARID AMPHIPODS
SPHAEROMATID ISOPODS
HIPPOLYTID SHRIMP
CHITONS & GRAZING GASTROPODS
GRAPSID CRABS
POLYCHAETE ANNELIDS
PELAGIC ZOOPLANKTON
PHORONID CLAMS
MEIOFAUNA (OSTRACODS, CUMACEANS, TANAIDS)
PAGURID CRABS
INSECT LARVAE
MICROPHYTIC ALGAE
MACROPHYTIC ALGAE
PHYTOPLANKTON
DETRITUS
*PLUS ZOOXANTHELLAE

Fig. 6. Composite food web characteristic of cobble littoral habitats in northern Puget Sound and the Strait of Juan de Fuca.

Detritus grazers still form the basis of the food web leading to the secondary carnivores. As in the rocky littoral, seasonal variation is slight (Appendix Tables E-5, E-6).

V-A-5 Gravel-Cobble Shallow Sublittoral Food Webs

Perhaps the most widespread and most common habitat in the overall study area, after the rocky littoral and rocky/kelp bed sublittoral habitats, is the gravel-cobble beach. Variations in this habitat are due to sediment size and exposure to wave action, which largely restrict the presence of macroalgae or eelgrass. In general, the food webs in this habitat tend to be the least diverse (in number of nodes) of all the food webs, but the most connected ($\bar{x}$ No. of linkages/node = 2.22) of all the exposed habitats (Fig. 7, Tables 2,3).

Even though this habitat does not typically support extensive macroalgal communities, detritus is apparently transported and accumulated in the unconsolidated sediments which act as a physical grinder, breaking up kelp and algal fragments into smaller particles easily utilized by detritivores. Detritus-grazing epibenthic crustaceans such as gammarid amphipods, cumaceans, and harpacticoid copepods, and mixed algae-detritus grazers such as mysids and flabelliferan and valviferan isopods were the most important elements of the lower trophic levels which supported the majority of the secondary consumers. Key species include the amphipods *Ischyrocerus anguipes*, *Paraphoxus* sp., *Melita desdichata*, *Paramoera mohri*, *Pontogeneia ivanovi*, *Hyale rubra frequens*; the cumaceans *Cumella* sp.; the mysid *Archaeomysis grebnitzki*; the flabelliferan isopods *Gnorimosphaeroma oregonensis*, *Exosphaeroma amplicauda*, and *Dynamenella sheareri*; and the valviferan isopods *Idotea wosnesenski*, *Synidotea* sp., and *Idotea montereyensis*. Gammarid amphipods supported 7 of the 10 epibenthic planktivores and accounted for 16 of the 46 linkages to secondary carnivores.

There are a number of variations in food web structure among the ten gravel-cobble habitat locations examined (Appendix Tables E-7, E-8). In general, the more protected the location, the more complex the community and food web structure. Relatively protected locations like Legoe Bay, Deadman Bay, and south Guemes Island appeared to have the highest number of food web nodes and linkages. At the other extreme, exposed sites like Alexander's Beach, Dungeness Spit, and Kydaka Beach indicated the least diversity. This is not always the case, however. Relatively exposed locations such as Cherry Point and South Beach exhibited more diverse food webs than might be expected. At Cherry Point, large boulders and sparse kelp beds (*Nereocystis*) immediately adjacent to the beach probably acted to diversify the habitat and decrease its exposure to wave action. Similarly, kelp beds were present offshore of the gravel-cobble beach at West Beach on the west coast of Whidbey Island. South Beach, on the southwestern shore of San Juan Island, exposed to the Strait of Juan de Fuca, is a high-energy beach with no such protection. The relatively high diversity of the community is therefore difficult to explain in the same manner. Some of the additional species may be attributed to the expansive sandflat habitat immediately offshore, but the complex food web documented in summer was still unexpected.

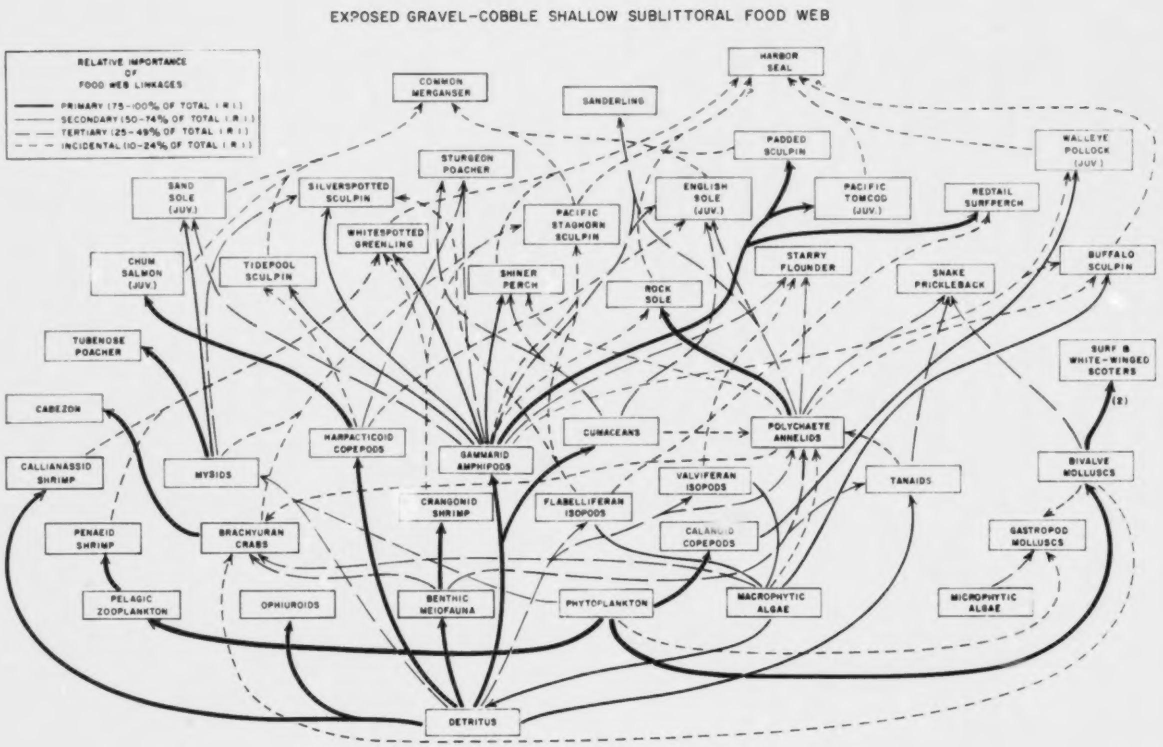

EXPOSED GRAVEL-COBBLE SHALLOW SUBLITTORAL FOOD WEB
RELATIVE IMPORTANCE OF FOOD WEB LINKAGES
PRIMARY (75-100% OF TOTAL I.R.I.)
SECONDARY (50-74% OF TOTAL I.R.I.)
TERTIARY (25-49% OF TOTAL I.R.I.)
INCIDENTAL (10-24% OF TOTAL I.R.I.)
COMMON MERGANSER
SANDERLING
HARBOR SEAL
STURGEON POACHER
PADDED SCULPIN
WALLEYE POLLOCK (JUV.)
SAND SOLE (JUV.)
SILVERSPOTTED SCULPIN
PACIFIC STAGHORN SCULPIN
ENGLISH SOLE (JUV.)
PACIFIC TOMCOD (JUV.)
REDTAIL SURFPERCH
WHITESPOTTED GREENLING
CHUM SALMON (JUV.)
TIDEPOOL SCULPIN
SHINER PERCH
ROCK SOLE
STARRY FLOUNDER
SNAKE PRICKLEBACK
BUFFALO SCULPIN
TUBENOSE POACHER
SURF & WHITE-WINGED SCOTERS
(2)
CABEZON
HARPACTICOID COPEPODS
GAMMARID AMPHIPODS
CUMACEANS
POLYCHAETE ANNELIDS
CALLIANASSID SHRIMP
MYSIDS
VALVIFERAN ISOPODS
TANAIDS
BIVALVE MOLLUSCS
CRANGONID SHRIMP
FLABELLIFERAN ISOPODS
PENAEID SHRIMP
BRACHYURAN CRABS
CALANOID COPEPODS
GASTROPOD MOLLUSCS
PELAGIC ZOOPLANKTON
OPHIUROIDS
BENTHIC MEIOFAUNA
PHYTOPLANKTON
MACROPHYTIC ALGAE
MICROPHYTIC ALGAE
DETRITUS

Fig. 7. Composite food web characteristic of exposed gravel-cobble, shallow sublittoral habitats in northern Puget Sound and the Strait of Juan de Fuca.

One obvious difference in food web structure among the various gravel-cobble locations was the increased importance of mysids at the locations along the Strait of Juan de Fuca. These shrimp-like epibenthic crustaceans (predominantly *Archaeomysis* sp.) appeared to supplant the role of gammarid amphipods as prey for many epibenthic carnivores in this region. It cannot be established, however, whether this is a result of increased exposure at sites in the western portion of the strait or of the greater influence of oceanic environment. Cumaceans (*Cumella* sp.) also tended to be more important in the strait.

Seasonal variations are not consistent (Appendix Tables E-7, E-8). In many locations there is a greater food web diversity evident in summer and fall, especially at some of the north Puget Sound locations. Locations in the strait, however, maintain approximately the same number of food web nodes throughout the year, even though there is usually an increase in the total number of food web linkages in summer.

V-A-6 Sand/Eelgrass Food Webs

Sand/eelgrass habitats generally represent more protected versions of the gravel-cobble habitat. They are shallow, semi-enclosed embayments which have low- to moderate-energy beaches, allowing sand and mixed fine gravel to accumulate and stabilize. Only one the sites typified a moderate- to high-energy location--Eagle Cove on the western shore of San Juan Island. The principal characteristic is the presence of "beds" of the seagrass *Zostera marina*.

The influence of the more stable substrate is illustrated in the community and food web structure (Fig. 8). Benthic infauna and epibenthic fauna which inhabit the top layers of the bottom sediments are more prevalent, as are carnivores which prey on benthic forms. In addition, the increased abundance of small epibenthic crustaceans (harpacticoid copepods, cumaceans, tanaids) provides the necessary prey resources for juvenile demersal fishes which can seek protection from predation among the eelgrass beds and in the shallow waters.

Eelgrass is responsible in many ways for the complexity of the food web, which has the second highest average number of linkages per node, even though the total number of nodes is only average (Tables 2,3). As a structural habitat, eelgrass increases the substrate available for the growth of epiphytic algae and associated fauna, reduces wave and current action, traps sediments and detritus, maintains high dissolved oxygen concentrations through photosynthetic activity, and by shading at low tide minimizes fluctuating temperatures that would be induced by direct sunlight (Kikuchi and Peres 1977). More important, eelgrass and its associated epiflora provide great quantities of detrital carbon to the nearshore system through autumn die-back and atrophy of the emergent growth.

Detritus, which is presumably eelgrass-derived to a great extent, provides energy directly to detritivores and indirectly to primary carnivores preying on benthic meiofauna. Important detritivorous crustaceans include harpacticoid copepods; the gammarid amphipods

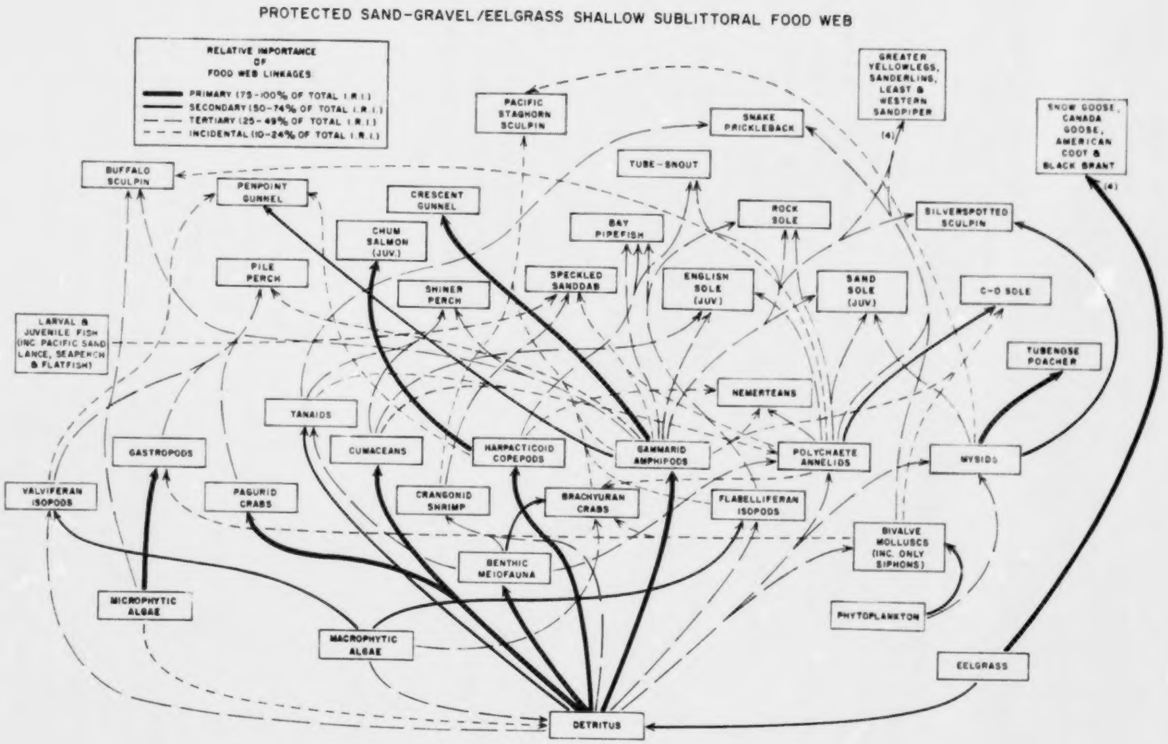

PROTECTED SAND-GRAVEL/EELGRASS SHALLOW SUBLITTORAL FOOD WEB
RELATIVE IMPORTANCE OF FOOD WEB LINKAGES
PRIMARY (75-100% OF TOTAL I.R.I.)
SECONDARY (50-74% OF TOTAL I.R.I.)
TERTIARY (25-49% OF TOTAL I.R.I.)
INCIDENTAL (10-24% OF TOTAL I.R.I.)
PACIFIC STAGHORN SCULPIN
SNAKE PRICKLEBACK
GREATER YELLOWLEGS, SANDERLING, LEAST & WESTERN SANDPIPER
(4)
SNOW GOOSE, CANADA GOOSE, AMERICAN COOT & BLACK BRANT
(4)
BUFFALO SCULPIN
TUBE-SNOUT
PENPOINT GUNNEL
CRESCENT GUNNEL
ROCK SOLE
SILVERSPOTTED SCULPIN
BAY PIPEFISH
CHUM SALMON (JUV.)
PILE PERCH
SPECKLED SANDDAB
ENGLISH SOLE (JUV)
SAND SOLE (JUV)
C-O SOLE
SHINER PERCH
LARVAL & JUVENILE FISH (INC. PACIFIC SAND LANCE, SEAPERCH & FLATFISH)
TUBENOSE POACHER
NEMERTEANS
TANAIDS
CUMACEANS
HARPACTICOID COPEPODS
GAMMARID AMPHIPODS
POLYCHAETE ANNELIDS
MYSIDS
GASTROPODS
VALVIFERAN ISOPODS
PAGURID CRABS
CRANGONID SHRIMP
BRACHYURAN CRABS
FLABELLIFERAN ISOPODS
BIVALVE MOLLUSCS (INC. ONLY SIPHONS)
BENTHIC MEIOFAUNA
MICROPHYTIC ALGAE
PHYTOPLANKTON
MACROPHYTIC ALGAE
EELGRASS
DETRITUS

Fig. 8. Composite food web characteristic of protected sand/eelgrass, shallow sublittoral habitats in northern Puget Sound and the Strait of Juan de Fuca.

Anisogammarus confervicolus, *Pontogeneia* sp., *Ischyrocerus anguipes*, *Paraphoxus* sp., *Photis brevipes*, *Aoroides* sp., *Atylus tridens*, and *Podoceropsis inaequistylus*; the tanaid *Leptochelia dubia*; the leptostracan *Nebalia pugettensis*; the cumacean *Cumella vulgaris*; and pagurid crabs *Pagurus* sp. Crustaceans which are able to utilize both detritus and epiphytic macroalgae include the flabelliferan isopods *Gnorimosphaeroma oregonense* and *Exosphaeroma* sp., and the valviferan isopod *Synidotea nodulosa*. Primary carnivores upon benthic meiofauna include crangonid shrimp, crabs, tanaids, and polychaete annelids.

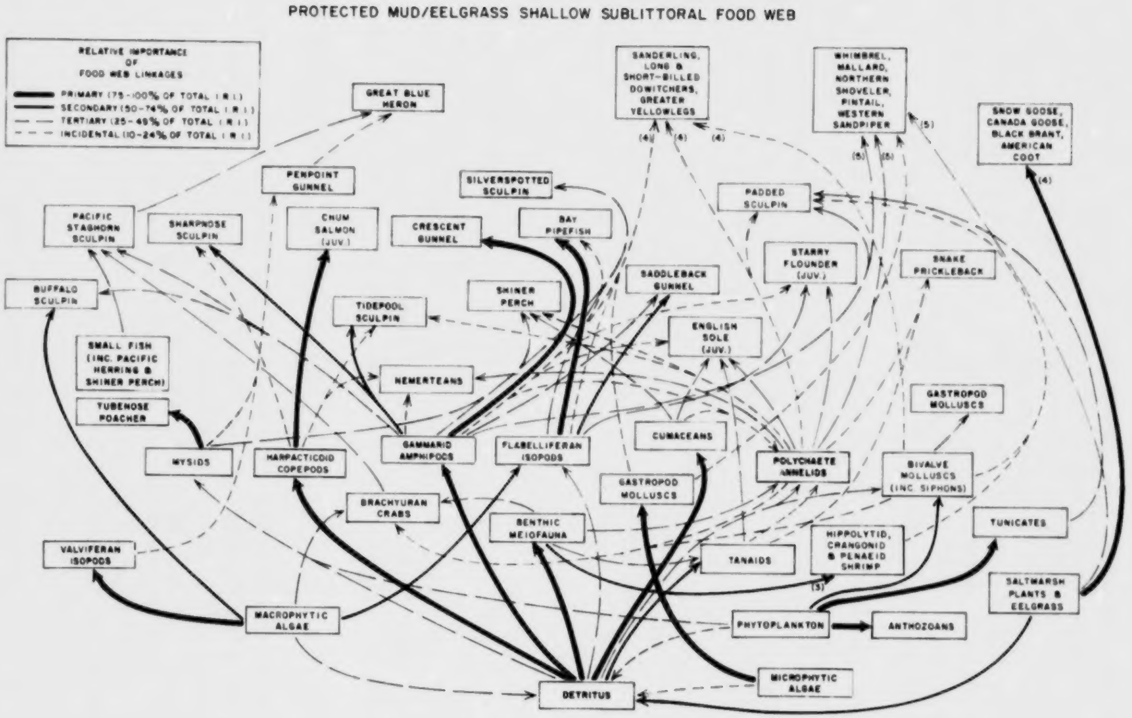
Of the secondary carnivores which exploit the diverse epibenthic and benthic fauna, juvenile and adult flatfish are one of the most important groups, including juvenile English sole and sand sole, and adult rock sole. Other species compose an assemblage which is apparently characteristic of eelgrass beds, including shiner perch, bay pipefish, penpoint gunnel, and tube-snout. It is in this habitat, as well as in the mud/eelgrass habitat, that benthic-feeding shorebirds are prevalent--greater yellowlegs, sanderling, least sandpiper, and western sandpiper. As the only true herbivores upon the eelgrass, Canada geese, American coot, and black brant commonly inhabit the sand/eelgrass habitats during their seasonal stay in the region.

In general, the sand/eelgrass communities and food webs at the different locations have the same structure (Appendix Tables E-9, E-10). Birch Bay appears to be slightly more diverse in structure than the other three sites, mainly because of a greater number of benthic carnivores. Pacific sanddab, whitespotted greenling, and buffalo sculpin were common in this habitat only at Birch Bay. Other important differences were the absence of herbivorous waterfowl in the western Strait of Juan de Fuca (where the eelgrass beds are reduced and sparser than in north Puget Sound and the eastern strait) and the presence of redtail surfperch only in the western Strait of Juan de Fuca. There is no definite pattern in the seasonal variability of the number of food web nodes or linkages.

V-A - 7 Mud/Eelgrass Food Webs

Undoubtedly, the most complex and highly connected habitat is the mud/eelgrass habitat and the saltmarsh environment often associated with it (Fig. 9). Overall, the highest number of food web nodes and linkages and the highest average number of food web linkages per node were found for this habitat (Tables 2, 3). Most of the increase, as compared with the sand/eelgrass habitat, originates at the carnivore level where there are twice as many incidental linkages leading to the secondary carnivores. The principal reason for the increase is the presence of the benthic-feeding shorebirds (sanderling, longbilled dowitcher, shortbilled dowitcher, greater yellowlegs). At the tertiary consumer level, the great blue heron preys on a number of demersal fishes.

The principal species involved in the food web transfer are basically the same as in the sand/eelgrass habitat. It would appear that, rather than an increase in species richness, the actual production is higher, resulting in higher densities of each taxon. If there is any increase in species or functional groups in the mud/eelgrass habitat it is probably to be found in small epibenthic zooplankton and meiofauna. Nyblade's (1977,


PROTECTED MUD/EELGRASS SHALLOW SUBLITTORAL FOOD WEB

RELATIVE IMPORTANCE OF FOOD WEB LINKAGES
PRIMARY (75-100% OF TOTAL (R.I.)
SECONDARY (50-74% OF TOTAL (R.I.)
TERTIARY (25-49% OF TOTAL (R.I.)
INCIDENTAL (10-24% OF TOTAL (R.I.)
GREAT BLUE HERON
SANDERLING, LONG & SHORT-BILLED DOWITCHERS, GREATER YELLOWLEGS
WHIMBREL, MALLARD, NORTHERN SHOVELER, PINTAIL, WESTERN SANDPIPER
SNOW GOOSE, CANADA GOOSE, BLACK BRANT, AMERICAN COOT
(4)
(5)
PENPOINT GUNNEL
SILVERSPOTTED SCULPIN
PADDED SCULPIN
PACIFIC STAGHORN SCULPIN
SHARPNOSE SCULPIN
CHUM SALMON (JUV.)
CRESCENT GUNNEL
BAY PIPEFISH
STARRY FLOUNDER (JUV.)
SNAKE PRICKLEBACK
BUFFALO SCULPIN
TIDEPOOL SCULPIN
SHINER PERCH
SADDLEBACK GUNNEL
ENGLISH SOLE (JUV.)
SMALL FISH (INC. PACIFIC HERRING & SHINER PERCH)
NEMERTEANS
GASTROPOD MOLLUSCS
TUBENOSE POACHER
MYSIDS
HARPACTICOID COPEPODS
GAMMARID AMPHIPODS
FLABELLIFERAN ISOPODS
CUMACEANS
POLYCHAETE ANNELIDS
BIVALVE MOLLUSCS (INC. SIPHONS)
BRACHYURAN CRABS
GASTROPOD MOLLUSCS
BENTHIC MEIOFAUNA
TUNICATES
VALVIFERAN ISOPODS
TANAIDS
HIPPOLYTID, CRANGONID & PENAEID SHRIMP
SALTMARSH PLANTS & EELGRASS
MACROPHYTIC ALGAE
PHYTOPLANKTON
ANTHOZOANS
MICROPHYTIC ALGAE
DETRITUS

Fig. 9. Composite food web characteristic of protected mud/eelgrass, shallow sublittoral habitats in northern Puget Sound and the Strait of Juan de Fuca.

1978) documentation of the littoral and shallow sublittoral benthic communities shows that although the species richness may be slightly higher in the lower intertidal levels of the mud/eelgrass habitat, the densities and biomass of organisms usually are appreciably higher than in the sand/eelgrass habitat. Neither the DOE nor the MESA sampling design quantified organisms such as epibenthic zooplankton or meiofauna; therefore, this difference may be more pronounced than indicated. MESA-sponsored epibenthic plankton sampling during August 1978 along the strait (Simenstad and Kinney, in prep.) also substantiates the fact that epibenthic crustaceans such as harpacticoid copepods less than 1 mm in size are much denser in the mud/eelgrass habitat at Jamestown and Point Williams than in the sand/eelgrass habitat at Beckett Point (crustaceans in DOE and MESA benthos studies sieved down to 1 mm; the epibenthic plankton pumping filtered to 0.209 mm). Furthermore, densities were almost five times higher within the eelgrass bed than in the base sediment.

One possible reason for the high benthic diversity and production, in addition to the sediment particle size and its ability to entrain organic matter, is the input of organic detritus from the saltmarshes which usually occur in the estuarine end of the contained embayments in this region. This vascular-plant vegetation perennially produces high biomasses of organic material which tends to accumulate on the mudflat and partly decompose there, and then is transported into the estuary with the spring runoff and spring tides. A lag of 14 months between peak carbon uptake by the saltmarsh vegetation and eventual flushing into the estuary has been documented for saltmarsh ecosystems on the Atlantic coast (Hopkinson and Day 1977).

Perhaps because the habitat is protected, there are no distinct indications of seasonal change in food web structure or diversity. Differences in food web structure between the three mud/eelgrass locations are minimal except for the relative unimportance of flabelliferan isopods at the Strait of Juan de Fuca location (Jamestown - Port Williams) as compared to their prominance in the food webs in north Puget Sound.

V-B. Prey Assemblages of Major Importance to Upper Trophic Levels

Several functional groups or taxa of organisms stand out as important energy sources or prey resources for upper trophic levels (Table 4). The criteria determining importance are that the organisms (1) provide the majority of the energy sources for consumer organisms at some time, (2) provide important conversion or transfer of organic matter to trophic levels where it is available to higher level consumers, or (3) hold "keystone" roles in structuring the composition of the community and the directions and rates of food web energy flow.

The simple but extensive transfer of phytoplankton biomass to planktivorous neritic fishes by calanoid copepods is a prime example. Calanoids rapidly convert autotrophic carbon into high density plankton particles which are utilized by dense larval and juvenile neritic fishes, especially herring and Pacific sand lance. These carnivores are in turn the principal prey of the alcid seabirds and several marine mammals. This calanoid chain, unlike the detritus-based chain, is characterized

Table 4. General listing of species or functional groups which are of major importance to the upper trophic levels of the nearshore food webs of northern Puget Sound and the Strait of Juan de Fuca. See text for criteria determining importance.

Primary energy sources	Decomposers	Herbivores
Diatoms:	Fungi	Calanoid copepods:
	Bacteria	
Chaetoceros sp.	Flagellates	*Acartia longremis*
Skeletonema costatum		*Calanus marshallae*
Thalassiosira sp.		*C. plumchrus*
		Epilabidocera amphitrites
Macroalgae:		*Microcalanus* sp.
		Oncaea borealis
Nereocystis sp.		*Paracalanus* sp.
Laminaria sp.		*Pseudocalanus* sp.
Vascular plants:		Cyclopoid copepods:
Zostera marina		*Oithona similis*
		Euphausiids:
		Euphausia pacifica
		Thysanoessa longipes
		T. spinifera
		Sea urchins:
		Strongylocentrotus sp.
		Polychaete annelids:
		Platynereis sp.
		Lumbrineris sp.
		Molluscs:
		Lacuna sp.
		Acmaea sp.
		Transenella sp.
		Katarina tunicata
		Mopalia sp.
		Littorina sp.
		Mytilus sp.
		Balanus sp.

Table 4, cont'd

Detritivores	Primary carnivores	Secondary and tertiary carnivores
Harpacticoid copepods:	Seastars:	Fishes:
Amphiascoides cinctus	*Pisaster* sp.	*Ophiodon elongatus*
Dactylopodia sp.	*Leptasterias* sp.	
Ectinosomidae		
Harpacticus uniremis	Fishes:	
Huntemannia jadensis		
Tisbe sp.	*Ammodytes hexapterus*	
Zaus sp.	*Anoplarchus purpurescens*	
	Clupea harengus pallasi	
Gammarid amphipods:	*Cymatogaster aggregata*	
	Gobiesox maeandricus	
Amphithoe simulans	*Hypomesus pretiosus*	
A. lacertosa	*Leptocottus armatus*	
Aoroides columbiae	*Oligocottus maculosus*	
Atylus tridens	*Oncorhynchus keta*	
Anisogammarus sp.	*O. kisutch*	
Eohaustorius sp.	*O. tshawytscha*	
Erichtonius brasiliensis	*Parophrys vetulus*	
Eusiroides sp.	*Psettichthys melanostictus*	
Hyale rubra	*Spirinchus thaleichthys*	
Ischyrocerus sp.		
Callipiella pratti		
Melita desdichata	Molluscs:	
Paramoera mohri		
Paraphoxus sp.	*Octopus dofleini*	
Parapleustes pugettensis	*Thais* sp.	
Photis brevipes		
Pontogeneia sp.	Polychaete annelids:	
Flabelliferan isopods:	*Dorvillea* sp.	
	Glycera sp.	
Dynamenella sheareri	*Hemipodus* sp.	
Exosphaeroma amplicauda	*Micropodarke* sp.	
Gnorimosphaeroma oregonense	*Nephtys* sp.	
	Ophiodromus sp.	
	Phyllodocidae	
Idoteid isopods:	*Protodorvillea* sp.	
Idotea wosnesenski		
I. montereyensis		
I. urotoma		
Synidotea sp.		

Table 4, cont'd

Detritivores, cont'd

Mysids:

Acanthomysis sp.
Archaeomysis grebnitzki
Holmesiella anomala
Neomysis mercedis

Cumaceans:

Cumella sp.

Tanaids:

Leptochelia dubia

Leptostracans:

Nebalia pugettensis

Shrimp:

Crangon sp.
Hippolyte sp.
Lebbeus sp.
Spirontocaris sp.
Heptacarpus sp.

Polychaete annelids:

Capitellidae
Cirratulidae
Paraonidae
Spionidae

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by high turnover rates, high energy demands on the part of the consumers, and a relatively contracted time scale--in spring and early summer when the spring phytoplankton blooms develop, the larval fish enter the neritic environment, and the alcids are scouring the neritic fish communities for food for their nestlings.

Overall, the most consequential organisms to nearshore food webs were gammarid amphipods, which dominated the detritivore group in every environment except the neritic. Although the taxonomic documentation of this diverse group of crustaceans is very incomplete, we have distinguished a number of genera which appear to be critical participants in the food web.

Other important detritivorous crustaceans are harpacticoid copepods, flabelliferan and idoteid isopods, cumaceans, mysids, tanaids, leptostracans, and shrimps.

Of the carnivores, besides Pacific herring and Pacific sand lance already mentioned, shiner perch, Pacific staghorn sculpin, tidepool sculpin, surf smelt, longfin smelt, salmon (principally juvenile chum, coho, and chinook), juvenile sand sole, and northern clingfish were identified as contributing a significant proportion of the primary and secondary food web linkages to tertiary carnivores. Octopus and lingcod are important predators on sublittoral fish and invertebrate communities, and themselves are utilized by marine mammals and man. In the shallow sublittoral habitats, several seastars, gastropods, and polychaete annelids by preferentially feeding on certain components of the lower trophic levels determine the course of competitive interactions, regulate the community structure, and influence the pathways of trophic energy flow.

V-C. Relative Importance of Autotrophic Versus Heterotrophic Energy Bases to Nearshore Food Webs

The importance of detritus as a carbon source for consumer organisms is readily apparent from our documentation of the nearshore food webs of north Puget Sound and the Strait of Juan de Fuca. Only in the neritic food webs do autotrophic (phytoplankton) sources provide more numerous and more important linkages to consumers than detritus, and even in this case many herbivores are functionally capable of exploiting both phytoplankton and detritus particles. Even in the neritic food web, the established paradigm of the dominant role of phytoplankton production is becoming increasingly challenged in favor of microbial utilization of dissolved organic matter and non-living organic particles (Pomeroy 1974). Although much of the macroalgae and vascular plant vegetation in the nearshore environs are directly grazed by herbivores such as sea urchins, isopods, and brachyuran crabs, the majority of the first level consumers are detritivores. Thus, while some autotrophically produced biomass is directly transferred to higher trophic levels, the majority appears to reach maturity and detach and decompose in the nearshore region, eventually providing a pool of suspended and dissolved organic matter available for heterotrophic conversion to decomposer biomass. The apparent unimportance of food web transfer by herbivory may be partly due to the control of herbivores by predators. Much of the reason may also lie in the fact that most marine invertebrates cannot digest structural polysaccharides because they lack adequate digestive enzymes (Kristensen 1971). In the case of eelgrass, the only significant grazers appear to be sea urchins (uncommon in the eelgrass beds of this region) and herbivorous waterfowl such as the black brant (Kikuchi and Peres 1977). Even in the case of benthic macroalgae, herbivores may cycle more biomass into the detritus "pool" by detaching large pieces of algae from the substrate in the act of grazing the holdfasts.

Just as live macroalgae cannot be used by grazing invertebrates, subsequent detritus particles also are not directly convertible. Structural and nutritional decomposition of the particles by microflora such as marine bacteria appears to be a critical process in conditioning the detritus before utilization by detritivorous fauna. As has been recently established, the associated microflora may be the actual food source of the detritivores (Mann 1972; McRoy 1970; Brown and Sibert 1977; McIntyre 1969; Seki 1966).

Other recent investigations into the trophic structure of food webs characterizing estuaries and coasts have also pointed to the importance of the transfer of primary production into detritus and the linkages between the detrital carbon, the associated microflora, the detritus-stripping fauna, and the fishes which feed on them (Williams, et al., 1968; Odum 1970; Qasim and Sankaranrayanan 1972; Shubnikov 1977; Simenstad, et al., 1977).

Thus, the dynamics and mechanisms of the processes which determine (1) the transport of detritus sources into the estuarine and nearshore environment, (2) the physical and chemical conditioning of the detritus, and (3) the development of microflora on the detritus particles will dictate how detritus-based food webs can be altered by pollutant effects or how pollutants may be transferred to higher trophic levels through detritus particles. In general, these processes are poorly understood and seldom quantified.

V-D. Ecological Impact of Introduction or Incorporation of Petroleum Hydrocarbons Into Nearshore Food Web Structures of North Puget Sound and the Strait of Juan de Fuca

Petroleum hydrocarbons in the nearshore habitats of north Puget Sound and the Strait of Juan de Fuca could disrupt both the structure and the energy flow dynamics of their marine food webs. The resulting ecological effects would vary according to the quantity and type of petroleum spilled and the conditions of weathering and biodegradation before and after the petroleum impacts the habitat. The potential for extensive and long-lasting alterations to the food web would in turn depend on which nearshore habitats are impacted and the season in which the incident occurred.

A brief introduction to the documented toxic effects of petroleum hydrocarbons to temperate marine organisms is in Appendix F. The existing knowledge of petroleum effects on marine organisms and ecosystems, and documentation of the observed effects of accidental oil spills, has been utilized to assemble the following description of the most probable and serious ecological effects which could be imposed on the nearshore food webs of the region.

Disruption or alteration of a food web could occur through several mechanisms: (1) Selective elimination of species or functional groups which provide important food web linkages to higher trophic levels, (2) disruption of key processes which control the conversion of non-utilizable carbon into biomass available for consumption by lower trophic level organisms, (3) selective elimination or reduction in populations of "keystone" predators (Paine 1969) or "foundation" species (Dayton 1972) which control or dominate competitive interactions between components of lower trophic levels, and (4) sublethal effects on metabolic activity, behavior, growth, and reproduction causing key species to lose their competitive advantage or reducing their effectiveness as predators or herbivores. Also to be considered is effects via inter-food web relationships, where disruptions in one community may eventually result in disruption of the food web in another community. This is particularly evident where a species occurs in one habitat as a juvenile and in another as an adult. Examination of the region's food web structures indicates there is viable potential for alteration through several mechanisms.

One of the most obvious cases is that of the short, simple food web involving neritic phytoplankton, herbivorous calanoid copepods, and planktivorous fishes, specifically Pacific herring and Pacific sand lance. Discussions in Appendix F point out that levels of prey abundance and size are critical determinants of fish survival during the transition from larval to juvenile stages. It is also at this stage that these raptoral planktivores are probably least able to switch to alternative prey organisms without significant cost in survival. Specifically, the populations of small surface-dwelling calanoids (Pseudocalanus sp., Microcalanus sp., Oithona sp.), which are the group most vulnerable to acute toxic effects from spilled petroleum in neritic habitats, provide the high density prey aggregations which larval Pacific herring, Pacific sand lance, surf smelt, and longfin smelt depend on. This highly structured predator-prey linkage may specifically include the early life history (nauplius, copepodite) stages of these small calanoids, which are most densely aggregated in the upper surface (0 m to -10 m) and which may form the limited size fractions (less than 0.500 mm) the larval fish first feed on. High densities of adult Pseudocalanus sp., Microcalanus sp., and Oithona sp. extend down to approximately -25 m (Mark Ohman, UW Dept. Ocean.), so it is improbable that the total population of adults would be severely depleted by the toxic effects of soluble petroleum components diffusing from the surface. The extent of depletion would depend on the extent of surface mixing of the water column. However, we do not know whether the larval fishes, still relatively planktonic at that stage, are functionally entrained in the top surface layers and vulnerable to toxic hydrocarbons or subject to reduction in the only food resources available to them. In any case, considering the potential vulnerability of these larval fishes and their unique prey resources and the contribution the neritic fishes make to upper trophic levels, the potential for significant and long-term food web disruption is extremely high during March through June when the larvae occupy the region's surface waters.

The later juvenile stages of these neritic fishes, as well as juvenile salmonids (coho, chinook, and pink salmon) which continue to occupy neritic habitats through late fall and early winter, do not appear to be as vulnerable to the effects of spilled petroleum hydrocarbons. By this stage their diet, though still selective by prey size, has become more diverse. In most cases, large calanoid copepods (Calanus sp.) which ascend from deep water populations constitute the majority of their diet. Thus, although these preferred prey may be locally depleted, there is still the diel migration of prey from unaffected populations in deep water to resupply the surface waters. Only two prey taxa would be severely affected by surface-oriented pollutants such as oil--drift terrestrial insects, prominent in the diet of juvenile chinook salmon, and the neustonic calanoid copepod Epilabidocera amphitrites, which are preferentially consumed by all juvenile salmonids during daylight foraging. The capability of temporarily switching to other appropriate prey--even though they may not provide optimal energy (caloric) content for the energy required to capture them--would probably enable these fishes to obtain alternate prey without adverse effects.

The previous impacts have involved acute toxic effects responsible for immediate elimination or reduction in predator-prey linkages. Sublethal effects may also be manifested in the neritic food web and could contribute to long-term effects through several generations of prey and predator populations. Through the consumption of petroleum hydrocarbon-contaminated copepods, neritic fishes could accumulate enough hydrocarbons or their metabolic byproducts to affect behavior or reproduction. Thus, recruitment of ecologically and commercially important species could be adversely affected through the lifetime of the yearclass* and its progeny. This transfer of contaminants does not stop at the neritic fishes, of course. As noted earlier, they support major trophic linkages to alcid seabirds and marine mammals that could subsequently suffer adverse sublethal effects similar to those described for the fishes.

In the case of the nearshore littoral and shallow sublittoral food webs, we envision the potential for one of the most deleterious impacts from spilled petroleum reaching nearshore habitats. Considering the obvious importance of detritus to all the region's nearshore food webs, any disruption or contamination of the detritus pool, its replenishment from macroalgae and eelgrass or the physical-biological process of decomposition and colonization by microorganisms implies extensive, long-term alterations of the structure of the food web or its productivity. While growth of sulfide-generating bacteria may be enhanced by the adsorption of petroleum by detritus particles, the deleterious sublethal effects on detritivorous zooplankton and meiofauna (harpacticoid copepods, gammarid amphipods, cumaceans, shrimps, tanaids, leptostracans, polychaete annelids, oligochaetes) may more than compensate for any possible benefit due to increases in microbial activity. Although the populations of the detritivores may not be directly (acutely) affected as a result of their stripping of hydrocarbons off the detritus particles, incorporation of hydrocarbons into their tissues would probably result in some decrease in reproductive potential. Reduction in the density of epibenthic detritivores could in turn reduce the importance of the linkages leading to many of the carnivores which feed upon these numerous epibenthic organisms. During certain seasons (especially late spring to early summer) the carnivore compartment includes juvenile stages of many ecologically or commercially important species (i.e., English sole, chum salmon, staghorn sculpin, tidepool sculpin) which utilize the shallow sublittoral zone as a nursery area, partly because the epibenthic organisms form appropriate prey items.

The persistence of this impact will be determined in part by the availability of the petroleum hydrocarbon to weathering and biodegradation. This has been shown to be particularly associated with the degree of unconsolidated sediments characterizing the habitat where the petroleum has accumulated. The most extreme case documented to date is evidenced by the prolonged incorporation of hydrocarbons into soft sediments generally associated with estuaries and marshlands. This has been well illustrated by the history of the West Falmouth spill of No. 2 fuel oil in 1969. Long-term documentation of the effects has indicated that petroleum degradation in the soft-bottom saltmarsh habitats occurs slowly, especially below the surface of the bottom sediment (Blumer and Sass 1972). Almost seven years after this relatively small spill was stranded in the area's marshlands there was evidence of aromatic hydrocarbons present in the marsh sediments at concentrations above background (Teal, et al., 1978). While the lighter aromatics were responsible for immediate and toxic effects upon benthic organisms, such as the trophically important fiddler crab *Uca pugnax*, long-term reductions in crab density, sex ratio changes, reduced juvenile recruitment, high overwinter mortalities, hydrocarbon assimilation into tissues and behavioral abnormalities appear to have resulted from extended contact to sublethal concentrations entrained within the sediments (Kreb and Burns 1977). Thus, even though more resistant fauna were able to recolonize the surface, subsurface sediments still showed oil below 2.5 cm was fresh and presumably toxic after 24 months as the oil at the surface was after 10 months.

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*Yearclass denotes those fish of a species which were spawned during one year and are usually identified through an analysis of the population's age structure.

Thus, detritivorous benthic meiofauna, which either graze the detritus particles in the interstitial water or filter the water completely, may thus be continually subjected to hydrocarbons leaching from the lower sediments (Roesijadi et al. 1978). In addition to the infaunal species, the many epibenthic organisms residing in the top sediment layer (often referred to as the flocculent layer), by their periodic migration into the water column where they are susceptible to predation, act as transporters of still active hydrocarbons between the sediments and the water-column biota.

A third result which might be predicted from petroleum hydrocarbon pollution in the nearshore environs involves the selective mortality of the ecologically dominant species listed in Section V-C. These species by their selective predation on competitively dominant species at lower trophic levels or by their own competitive dominance play deterministic roles in structuring much of their nearshore community. In the first instance, elimination of predators such as seastars and gastropods, which control herbivore and sessile bivalve and barnacle populations, would probably result in the successive dominance by more efficient occupiers of space, thus reducing or eliminating macrobenthic algae. This effect could be profound, not only to the food web structure of those affected habitats but to any food web which is based on the detritus generated by the periodic die-off of these macroalgae. Those habitats in which macroalgae detritus collects and decomposes, even though the pollutant may not be impacting them, could have their food webs indirectly altered by the cessation or reduction of detritus input.

Alternately, in areas where herbivores are dominant such as in rocky sublittoral habitats occupied by sea urchins, removal or significant reduction in these herbivore populations would drive the benthic community more toward one dominated by macroalgae, with a likely decrease in diversity of benthic epifauna and a potential increase in detritivorous zooplankton such as mysids and gammarid amphipods.

When considering the potential for disruption of established food web structures by introduction of pollutants, questions of the food web's "stability" arise, its inherent susceptibility to collapse to a different, usually less diverse, structure under a perturbation (removal of linkages or nodes), and whether or not the food web is actually "unstructured," i.e., carnivores randomly utilize energy from the mean composition of the food web above the primary production level (Isaacs 1972, 1973). The concept that a community is proportionally more stable with increasing diversity of energy pathways (increasing connectance) has become an established paradigm (MacArthur 1955; Watt 1964) although more recent laboratory and mathematical modeling exercises have suggested that randomly connected systems tend to become less stable as the connectance increases (Gardner and Ashby 1970; May 1972, 1973). De Angelis (1975), however, has illustrated a number of plausible cases in which a similar food web model does show increased stability with increased connectance. While this argument still smolders among theoretical ecologists, there are inadequate empirical data, either laboratory or field, which have tested this hypothesis by perturbing a diverse spectrum of food webs. The most appropriate example is that of Paine's (1966) manipulation of rocky shore communities of Washington's exposed coast. In absence of such verification, the existing information suggests that elimination of certain community dominants and their associated food web linkages can result in dramatic alteration (decreased diversity and connectance) of the food web structure. As a result, relatively complex food webs should not necessarily be considered any more stable than less diverse food webs if pollutants can selectively impact populations of these dominant species or groups.

V-E. Comparison of Food Web Structures at Existing or Potential Oil Terminal Sites and an Evaluation of their Relative Importance

Four areas in northern Puget Sound and the Strait of Juan de Fuca have been considered for location of major oil transshipment facilities: Cherry Point, March Point (Anacortes), Burrows Bay, and Port Angeles (Ediz Hook). Discussion of the habitats and food webs of these areas will contribute information useful in evaluating these sites for such facilities.

The neritic food webs at the four areas are fairly similar in structure. However, food webs of the Anacortes area (Padilla Bay, Fidalgo Bay) tend to be more diverse in summer and less diverse in fall and winter than food webs of the other areas (Appendix Table E-1), mainly because of additional detritivores (valviferan isopods, cumaceans) and juvenile salmon in summer. Cherry Point had the greatest connectance ($\bar{X}$ number of linkages per node) during the spring, Port Angeles had the greatest in summer and fall, and Anacortes the greatest in winter. In terms of numerical abundance, however, the Cherry Point area (Cherry Point, Lummi Bay, Birch Bay) consistently exhibited the highest density and standing crop of neritic fishes during the DOE studies (Miller, et al., 1977; Fresh 1979) while the MESA collections in the Port Angeles vicinity were comparatively lower than in any other area (Simenstad, et al., 1977; Cross, et al., 1978). The high catches were principally due to high densities of postlarval Pacific herring which result from the sizable herring stock spawning adjacent to Cherry Point (Trumble, et al., 1977), although threespine stickleback and surf smelt also contributed to the high catches in this area. The Port Angeles area is also qualitatively different from the other three in several other ways, i.e., longfin smelt functionally replace surf smelt in the neritic fish assemblage and the tufted puffin is prominent.

The littoral habitats at Cherry Point, Burrows Bay, and Port Angeles are generally exposed, gravel-cobble beaches which grade into sand and sparse eelgrass in the shallow sublittoral zone. Food webs at all locations are based mainly on detritus and detritivorous crustaceans. Overall, Port Angeles shows the highest number of food web nodes in the spring and summer and Cherry Point appears to have the most diverse food web in the fall and winter (Appendix Table E-7). In terms of food web connectance, however, the Port Angeles area appears to have the highest average number of linkages per food web node during all seasons. The Cherry Point food web is based on gammarid amphipods which support a variety of epibenthic carnivorous fishes, while the food webs at Burrows Bay and Port Angeles are much more broadly based on detritivorous crustaceans (gammarid amphipods, cumaceans, harpacticoid copepods, pagurid crabs, hippolytid shrimp), suspension feeders (bivalves), and mixed food processors (mysids). In Burrows Bay and Port Angeles mysids become more important than gammarid amphipods in the diets of several prominent epibenthic carnivores that occur in all areas (e.g., Pacific staghorn sculpin, silverspotted sculpin).

The mud/eelgrass habitat which dominates the shallow sublittoral zone of March Point (Anacortes) has a much more diversified food web, possessing half again as many nodes as the food webs of the other areas (Appendix Table E-11). The average number of linkages per node is not appreciably different (Appendix Table E-12). Much of the increased complexity is due to the numerous seabirds and shorebirds which occupy the mudflats throughout the year. The tremendous abundance of waterfowl (black brant, snow goose, Canada goose) present from fall through spring feeding on eelgrass and saltmarsh plants, also increase the complexity. Benthic meiofauna and epibenthic detritivorous crustaceans and their predators effect the transfer of detrital carbon to upper trophic levels. Secondary consumers include one of the most diverse assemblages of nearshore fish of any habitat sampled during the DOE and MESA studies.

One of the main differences between this food web structure and the others is the extensive linkages between eelgrass and herbivorous waterfowl and the large annual contribution of eelgrass to the total detritus pool.

As regards vulnerability to ecological disruption from pollution, March Point shows the greatest sensitivity because of the diverse communities and productive food webs of its predominantly mud/eelgrass habitats. The unstructured sediments typical of this habitat would probably entrain toxic petroleum components for a long time and they would continue to leach into the epibenthic food web through the detritus-decomposer linkage. Loss of eelgrass would seriously limit the foraging of wintering waterfowl and dramatically alter the accumulation of detritus, the principal energetic source of the area's food web.

Cherry Point is the second most vulnerable area because of its extensive neritic food web. No other area in north Puget Sound or the Strait of Juan de Fuca produces as great a standing stock of post-larval neritic fishes, especially the commercially important Pacific herring. These fish are apparently restricted to nearshore habitats during the most sensitive stage of their life history, which means they would be vulnerable to both acute and sublethal effects of petroleum hydrocarbons. Overall, the north Puget Sound region is more vulnerable to long-term adverse effects of petroleum pollution because of the high proportion of contained embayments and eelgrass and saltmarsh habitats characterizing the nearshore region.

In the Strait of Juan de Fuca, the Port Angeles area exhibited the most highly connected food webs, which suggests that it would be less vulnerable to instability caused by removal of or reduction in food web linkages. The food web of the immediate area is more complex and productive than the food web identified at Burrows Bay. Also, increased exposure and more consolidated sediments than March Point would allow more weathering and degradation of spilled petroleum. Fewer toxic compounds, and in smaller amounts, would become incorporated in the sediments. The habitats adjacent to Port Angeles increase the area's overall vulnerability, however. The exposed gravel beach at Dungeness Spit and the mud/eelgrass and saltmarsh habitats behind the spit and at Discovery and Sequim bays to the east, are areas that would potentially suffer long-term effects from spilled oil, equal to those postulated for March Point. Dungeness Spit also provided the highest shallow sublittoral catches of juvenile salmon of the sites along the Strait of Juan de Fuca. These commercially important species may aggregate along the spit during their outmigration, which would expose them to any pollutant transported east from Port Angeles.

Burrows Bay characteristically had the least diverse and least productive food web of the four areas. The high energy of this embayment would probably cause considerable weathering of spilled petroleum. However, the MESA nearshore fish collections at Alexander's Beach also documented consistently high catches of juvenile chum salmon, suggesting that juvenile salmon migrating out of Skagit Bay through Deception Pass may aggregate in the bay.

V-F. Utilization of Empirical Food Web Data for Modeling Energy Flow in Marine Ecosystems

Although analysis of the structure of food webs provides measurable insights into the organization and importance of predator-prey linkages and inter-trophic-level transfers, only a comprehensive bioenergetic approach will ultimately produce clues to the dynamics of the system. Only the bioenergetic approach can generate predictions of the effects of perturbations on components of trophic levels. Bioenergentic analysis, however, requires relatively precise estimation of population density and standing crop levels of component species or functional groups and quantification of energy flow through predator-prey linkages in order to determine trophic, ecological, and population efficiency rates between and within trophic levels. Few natural systems have been empirically analyzed to this degree.

Although the limited data available for north Puget Sound and Strait of Juan de Fuca nearshore and neritic food webs do not allow so comprehensive an analysis, a preliminary analysis was performed on a component food web identifiable at one site in north Puget Sound--the mud/eelgrass, contained embayment habitat of Westcott Bay on San Juan Island. Low exposure, a relatively closed system, and DOE and other data (Thornburgh 1978) on top consumers and their prey made feasible the assembling of a simple energetic model for this site. The bay is used by several species of secondary consumers as a nursery area and the species assemblage might be considered typical of other mud/eelgrass sites in Puget Sound.

The results of this exercise (Appendix G), although not the product of a systematic experiment specifically designed and conducted to answer such questions, have illustrated significant gaps in our understanding of food web flow, ecological and assimilation efficiencies, food consumption and population integrity. Appearance of a 40-50X error factor between the annual consumption rate estimated from growth of juvenile English sole and estimated from their calculated daily consumption indicates that our basic knowledge of gastric evacuation and assimilation efficiencies is inadequate to meet the accuracy demanded by a bioenergetic model. Similarly, the standard techniques for estimating the standing stock of secondary consumers may also be inappropriate. What the exercise does show is that energy flow between prominent food web compartments (nodes) is quite sensitive to feeding behavior, including frequency of feeding on a specific prey, actual prey biomass consumed, periodicity and intervals in feeding, gastric evacuation rates, and the bioenergetic cost involved in the feeding process itself. Some of these functional relationships can be accurately estimated from well-designed laboratory experiments, but much will depend upon more precise quantification of the feeding of fishes and other high-level consumers in the environment.

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APPENDIX A: ALGAE AND INVERTEBRATES

Taxon: Genera	Regional # of species	Trophic level	References
Chlorophyta		Primary producers	
Volvocales: *Clamydomonas, Dunaliella, Thalassomonas*	9		29
Ulotrichales: *Blidingia, Enteromorpha, Entocladia, Internoretia, Monostroma, Percursia, Phaeophila, Ulothrix, Ulva*	27		29
Schizogoniales: *Prasiola, Rosenvingiella, Schizogonium*	3		29
Cladophorales: *Chaetomorpha, Cladophora, Lola, Rhizoclonium, Spongomorpha, Urospora*	23		29
Chlorococeales: *Chlorochytrium, Codiolum, Gomontia*	5		29
Codiales: *Bryopsis, Codium, Derbesia, Halicystis*	7		29
Bacillariophyta: Pennales	?	Primary producers	18
Phaeophyta *Agarum, Alaria, Analipus, Carpomitra, Coilodesme, Colpomenia, Compsonema, Costaria, Cymathere, Cystoseira, Desmarestia, Dictyoneuropsis, Dictyoneurum, Dictyosiphon, Dictyota, Ectocarpus, Egregia, Eisenia, Elachista, Eudesme, Feldmania, Fucus, Giffordia, Haplogloia, Hecatonema, Hedophyllum, Laminaria, Leathesia, Leptonematella, Lessoniopsis, Macrocystis, Melanosiphon, Myrionema, Nereocystis, Pelvetiopsis, Petalonia, Petroderma, Phaeostrophion, Pleurophycus, Postelsia, Pterygophora, Punctaria, Pylaiella, Ralfsia, Sargassum, Saundersella, Scytosiphon, Soranthera, Sphacelaria, Sphaerotrichia, Spongonema, Stictyosiphon, Streblonema, Syringoderma*	102	Primary producers	36

Taxon: Genera	Regional # of species	Trophic level	References
Rhodophyta *Acrochaetium, Aglaothamnion, Ahnfeltia, Amplisiphonia, Antithamnion, Antithamnionella, Arthrocardia, Asterocolax, Audouinella, Bangia, Besa, Bonnemaisonia, Bossiella, Botryocladia, Botryoglossum, Branchioglossum, Calliarthron, Callithamnion, Callocolax, Callophyllis, Caulocanthus, Ceramium, Chondrus, Choreocolax, Clathromorphum, Coeloseira, Conchocelis, Constantinea, Corallina, Cruoria, Cruoriopsis, Cryptonemia, Cryptopleura, Cryptosiphonia, Cumagloia, Cumathamnion, Delesseria, Dermocorynus, Dilsea, Endocladia, Erythrocladia, Erythrodermis, Erythroglossum, Erythrophyllum, Erythrotricia, Euthora, Farlowia, Fauchea, Faucheocolax, Fryeella, Gastroclonium, Gelidium, Gigartina, Gloiopeltis, Gloiosiphonia, Gonimophyllum, Goniotrichopsis, Goniotrichum, Gracilaria, Gracilariophila, Gracilariopsis, Grateloupia, Griffithsia, Gymnogongrus, Halosaccion, Halymenia, Harveyella, Herposiphonia, Heterosiphonia, Hildenbrandia, Hollenbergia, Holmesia, Hydrolithon, Hymenema, Iridaea, Janezewskia, Kallymenia, Kylinia, Laurencia, Leptofauchea, Lithophyllum, Lithothamnium, Lithothrix, Lomentaria, Lophosiphonia, Melobesia, Membranoptera, Mesophyllum, Microcladia, Myriogramma, Nemalion, Neoagardhiella, Neodilsea, Neopolyporolithon, Neoptilota, Nieburgia, Nitophyllum. Odonthalia, Opuntiella, Petrocelis, Peyssonelia, Phycodrys, Pikea, Platysiphonia, Platythamnion, Pleonosporium, Plocamium, Plocamiocolax, Polyneura, Polyneuropsis, Polysiphonia, Porphyra, Porphyrella, Porphyropsis, Prionitis, Pseudogloiophloea, Pseudolithophyllum, Pterochondria, Pterocladia, Pterosiphonia, Ptilota, Ptilothamniopsis, Pugetia, Rhodochorton, Rhodoglossum, Rhodomela,*	312	Primary producers	37

Taxon: Genera	Regional # of species	Trophic level	References
Rhodophysema, Rhodoptilum, Rhodymenia, Rhodymeniocolax, Sarcodiotheca, Scagelia, Scagelonema, Schizomenia, Serraticardia, Smithora, Stenogramme, Tenarea, Thuretellopsis, Tiffaniella, TraillieІla, Turnerella, Weeksia, Whidbeyella, Yamadaea			
Spermatophyta *Phyllospadix, Zostera*	4	Primary producers	16
Porifera		Suspension feeders on phytoplankton, bacteria, and small protozoans	3
Calcarea: *Leucosolenia, Scypha*	2+		19
Hexactinellida: *Aphrocallistes*	4		19
Demospongiae: *Cliona, Halichondria, Haliclona, Microciona, Mycale, Myxilla, Ophlitaspongia, Plocamia, Suberites*	39+		19
Cnidaria			
Hydrozoa		Hydroids suspension feeders on zooplankton; Medusae carnivores on zooplankton *Proboscidactyla* a commensal/ parasite on sabellid polychaetes	3
Hydroida: *Abietinaria, Aequorea, Bougainvilla, Campanulina, Clava, Coryne, Garveia, Gonionemus, Hydractinia, Phialidium, Plumularia, Proboscidactyla, Sertularella, Sertularia, Tubularia*	65+		19,13, 18
Trachylina	3		19
Hydrocorallina: *Stylantheca*	1		19
Chondrophora: *Velella*	1		19
Siphonophora	5		19
Scyphozoa		Primary/secondary carnivores on zooplankton and fish	3
Discomedusae: *Aurelia, Cyanea*	7		19
Stauromedusae: *Haliclystus*	2	Primary carnivores on caprellid amphipods	19,18
Anthozoa		Primary/secondary carnivores on zooplankton, fish, and benthic invertebrates	3
Stolonifera: *Clavularia*	1		19
Alcyonacea: *Gersemia*	1		19
Gorgonacea: *Paragorgia*	1		19

Taxon: Genera	Regional # of species	Trophic level	References
Pennatulacea: *Ptilosarcus*	3	Primary carnivores on zooplankton	19
Ceriantharia: *Pachycerianthus*	1		19
Zoanthiniaria: *Epizoanthus*	1		19
Scleractinia: *Balanophyllia*	2		19
Actinaria: *Anthopleura, Cribrinopsis, Diadumene, Epiactis, Halcampa, Metridium, Peachia, Stomphia, Tealia*	20	*Diadumene* and *Metridium* zooplanktivores; *Anthopleura* "farm" zooxanthellae, carnivores on benthic crustaceans and dislodged mussels	19,18, 30,15
Ctenophora: *Beroe, Bolinopsis, Pleurobrachia*	7	Primary carnivores on zooplankton; *Beroe* secondary carnivores on other ctenophores	
Platyhelminthes			
Cestoda	?	Entoparasites	3
Trematoda	?	Ecto- and ento-parasites	3
Turbellaria		Herbivores on diatoms; carnivores on small crustaceans	18
Acoelida	3+	Herbivores on diatoms; carnivores on protozoans and copepods	19,15, 3
Polycladida: *Kaburakia, Notoplana*	20	Carnivores on small crustaceans, gastropods, worms, and ascidians	19,18, 15
Neorhabdocodida	7+	Some commensals in sipunculans, crinoids, echinoids, and holothuroids	19
Proseriata: *Itaspiella*	8+		19
Tricladida: *Procerodes*	4+		19
Orthonectida	2	Parasites in ophiuroids and polychaetes	19

Taxon: Genera	Regional # of species	Trophic level	References
Dicyemida	4	Parasites in cephalopods	19
Nemertea: *Amphiporus*, *Cerebratulus*, *Emplectonema*, *Lineus*, *Malacobdella*, *Micrura*, *Paranemertes*, *Tubulanus*	26+	Primary carnivores on polychaetes, small molluscs, and crustaceans; *Paranemertes* up to 80% on *Platynereis*; *Malacobdella* commensal with *Siliqua*	19,18, 28
Rotifera	?	Suspension feeders on phytoplankton; primary carnivores on protozoans, rotifers, and other small metazoans	19,3
Gastrotricha	7+	Consumers of bacteria, diatoms and small protozoans	19,3
Kinorhyncha	7	Detritivores; herbivores on microalgae	19,3
Acanthocephala	?	Parasites on isopods and amphipods as juveniles; marine mammals, birds, and fish as adults	32,3
Nematomorpha	?	Parasites on decapod crustaceans	32,3
Nematoda	83+	Parasites; herbivores on microalgae; detritivores; primary carnivores on small metazoans	19,35, 3
Entoprocta: *Barentsia*	8	Suspension feeders on phytoplankton and small zooplankton	19,3
Mollusca			
Amphineura		Herbivores on microalgae	18,3,15
Acanthochitonidae: *Cryptochiton*	1		19,4
Callistoplacidae	2		19,4
Chaetopleuridae	1		19,4
Ishnochitonidae: *Cyanoplax*, *Ishnochiton*, *Tonicella*	10	*Tonicella* herbivores on microalgae and encrusting corallines	19,4, 18

Taxon: Genera	Regional # of species	Trophic level	References
Lepidopleuridae	2		19,4
Mopaliidae: *Katharina, Mopalia Placiphorella*	15+	*Placiphorella* carnivores on amphipods and shrimp as well as herbivores on microalgae	19,4,15
Gastropoda			
Prosobranchia			
Acmaeidae: *Acmaea, Collisella, Notoacmaea*	13	Herbivores on microalgae and encrusting macroalgae	19,4, 32,18
Lepetidae: *Cryptobranchia*	1	Herbivores on microalgae	19,4,32
Scissurellidae	1	Herbivores on microalgae	19,4,32
Haliotidae: *Haliotis*	1	Herbivores on microalgae	19,4,32
Fissurellidae: *Diodora, Puncturella*	9	Herbivores on microalgae	19,4,32
Trochidae: *Tegula, Calliostoma, Margarites, Lirularia*	14	Herbivores on microalgae; *Calliostoma* carnivores on hydroids	32,19, 4,32,18
Turbinidae: *Astraea, Homalopoma*	4	Herbivores on microalgae	19,4,32
Lacunidae: *Lacuna*	2	Herbivores on microalgae	19,4,18
Littorinidae: *Littorina*	3	Herbivores on microalgae	19,4,18
Rissoidae: *Alvinia, Barleeia*	6	Herbivores on microalgae	19,4
Assimineidae	1		19,4
Vitrinellidae	1	Commensals with chitons	19,4,32
Caecidae	2		19,4
Turritellidae	1		19,4
Vermetidae	3	Suspension feeders on phytoplankton	19,4,32
Cerithiidae: *Bittium, Cerithiopsis*	7+	Carnivores	19,4,32
Potamididae: *Batillaria*	1		19,4
Hipponicidae	2		19,4
Calyptraeidae: *Calyptraea, Crepidula, Crepipatella*	7	Suspension feeders on phytoplankton	19,4, 32,15
Trichotropididae: *Trichotropis*	1	Suspension feeders on phytoplankton	19,4
Naticidae: *Natica, Polinices*	5	Carnivores on thin-shelled bivalves, e.g., *Macoma*	19,4, 18,15

Taxon: Genera	Regional # of species	Trophic level	References
Lamellariidae	2	Carnivores on ascidians	19,4,32
Velutinidae	2	Carnivores on ascidians	19,4,32
Cymatiidae: *Fusitriton*	1	Carnivores on *Strongylocentrotus*, bivalves, chitons, asteroids	19,4,10
Epitoniidae: *Epitonium, Opalia*	4	Ectoparasites on anemones	19,4, 32,15
Eulimidae: *Balcis*	5	Ectoparasites	19,4,32
Thyonicolidae	3	Entoparasites in holothuroids	19,4
Muricidae: *Ceratostoma, Ocenebra, Urosalpinx, Borcotrophon*	9	Carnivores on barnacles, bivalves	19,4,18
Thaididae: *Thais (Nucella)*	3	Carnivores on small mussels and barnacles	19,4,33
Buccinidae: *Buccinum*	1	Carnivores	19,4
Neptuneidae: *Beringius, Colus, Neptunea, Searlesia*	7	Carnivores on bivalves; *Searlesia* carnivores and scavengers on barnacles, limpets, and chitons.	19,4,21
Columbellidae: *Amphissa, Mitrella*	4	Scavengers on dead animal tissue	19,4,18
Nassariidae: *Nassarius*	5	Carnivores	19,4
Volutidae	1	Carnivores	19,4
Mitridae	1	Carnivores	19,4
Marginellidae: *Granulina*	1	Carnivores	19,4
Olividae: *Olivella*	2	Scavengers on dead animal tissue	19,4,18
Cancellariidae: *Admete*	2	Carnivores	19,4
Turridae: *Oenopota, Ophiodermella*	11	Carnivores on polychaetes	19,4,31
Opisthobranchia			
Bullidae: *Volvulella*	1		19,4
Acteocinidae: *Cylichna*	4		19,4
Atyidae: *Haminoea*	1		19,4
Philinidae	2		19,4
Gastropteridae: *Gastropteron*	1		19,4

Taxon: Genera	Regional # of species	Trophic level	References
Aglajidae: *Aglaja*	2	Carnivores on polychaetes, ostracods, amphipods, and small bivalves	19,4
Pyramidellidae: *Odostomia, Turbonilla*	21	Ectoparasites	19,4,32
Aplysiidae: *Phyllaplysia*	1		19,4
Clionidae: *Clione*	2		19,4
Elysiidae: *Elysia*	3		19,4
Stiligeridae: *Hermaea*	4		19,4
Pleurobranchidae: *Berthella*	1		19,4
Corambidae: *Corambe*	2	Carnivores on bryozoans (e.g., *Membranipora*)	19,4, 18,15
Dorididae: *Anisodoris, Archidoris, Cadlina, Diaulula, Discodoris, Rostanga*	9	Carnivores on sponges	19,4
Onchidoridae: *Acanthodoris, Onchidoris*	6	*Acanthodoris* carnivores on bryozoans, *Onchidoris* on barnacles	19,4,18
Polyceridae: *Polycera, Triopha, Laila*	6	Carnivores on bryozoans	19,4,18
Arminidae: *Armina*	1	Carnivores on *Ptilosarcus*	19,4,18,5
Dendronotidae: *Dendronotus*	8	Carnivores on hydroids, *D. irus* on *Pachycerianthus*	19,4,27
Dotonidae: *Doto*	3		19,4
Durauceliidae: *Duvaucelia* (*Tritonia*)	4	Carnivores on alcyonaceans and pennatulaceans (*Ptilosaraus*)	19,4,5
Fimbriidae: *Melibe*	1	Carnivores on small crustaceans (e.g., *Caprella*)	19,4,18
Aeolidiidae: *Aeolidia, Hermissenda*	2	Carnivores: *Aeolidia* on anemones, *Hermissenda* on sea pens, hydroids, and colonial tunicates	19,4,18
Cuthonidae: *Cratena, Cuthona*	4		19,4
Dironidae: *Dirona*	2	Carnivores on bryozoans, ascidians, and small snails	19,4,18
Flabellinidae: *Eubranchus*	7	Carnivores on hydroids	19,4,18
Zephyrinidae: *Antiopella*	2		19,4
Onchidiidae: *Onchidella*	1	Herbivores on microalgae	19,4

Taxon: Genera	Regional # of species	Trophic level	References
Pulmonata			
Ellobiidae: *Phytia, Assiminea*	2	Herbivores on microalgae	19,4
Siphonariidae: *Siphonaria*	1	Herbivores on microalgae	19,4
Bivalvia			
Nuculidae	1	Detritivores, deposit feeders	32,19, 4,3
Nuculanidae: *Nuculana, Yoldia*	7	Detritivores, deposit feeders	32,19, 4,3
Malletiidae	2	Suspension feeders on phyto-plankton	19,4,3
Glycymeridae	1	"	19,4,3
Philobryidae	1	"	19,4,3
Mytilidae: *Crenella, Modiolus, Musculus, Mytilus*	8	"	19,4,3
Pectinidae: *Chlamys, Hinnites, Pecten*	8	"	19,4,3
Anomiidae: *Pododesmus*	1	"	19,4,3
Limidae	1	"	19,4,3
Ostreidae: *Crassostrea, Ostrea*	3	"	19,4,3
Lucinidae	2	"	19,4,3
Ungulinidae	1	"	19,4,3
Thyasiridae	4	"	19,4,3
Kelliidae: *Kellia, Mysella*	5	"	19,4,3
Leptonidae: *Lasaea*	1	"	19,4,3
Carditidae: *Cardita, Glans*	5	"	19,4,3
Astartidae	3	"	19,4,3
Cardiidae: *Clinocardium*	5	"	19,4,3
Mactridae: *Mactra, Spisula, Tresus*	4	"	19,4,3
Solenidae: *Siliqua, solen*	2	"	19,4,3
Tellinidae: *Macoma, Tellina*	18	Detritivores, deposit feeders	19,4,3
Psammobiidae: *Gari*	1	Suspension feeders on phyto-plankton	19,4,3
Semelidae: *Semele*	1	"	19,4,3
Kelliellidae: *Turtonia*	1	"	19,4,3
Veneridae: *Transennella, Gemma, Tapes (Venerupis), Psephidia, Humilaria*	9	"	19,4,3

Taxon: Genera	Regional # of species	Trophic level	References
Petricolidae	1	Suspension feeders on phyto-plankton	19,4,3
Cooperellidae	1	"	19,4,3
Myidae: *Cryptomya, Mya, Hiatella, Panopea*	9	"	19,4,3
Pholadidae: *Netastoma, Penitella, Xylophaga, Zirfaea*	6	"	19,4,3
Teredinidae: *Bankia, Teredo*	2	"	19,4,3
Pandoridae	5	"	19,4,3
Lyonsiidae: *Lyonsia, Mytilimeria*	4	"	19,4,3
Thraciidae	4	"	19,4,3
Cuspidaridae: *Cardiomya*	2	"	19,4,3
Scaphopoda: *Dentalium, Cadulus*	6	Detritivores	19,4,3
Cephalopoda			
Sepiolidae: *Rossia*	1	Carnivores on shrimp and fish	19,4,7
Loliginidae: *Loligo*	1	Carnivores on small fishes and shrimp	19,4, 18
Gonatidae: *Gonatus*	1	Carnivores on small fishes and shrimp	19,4, 18
Onychoteutidae: *Moroteuthis*	1		19,4
Octopodidae: *Octopus*	3	Carnivores on crabs, bivalves, and gastropods	19,4, 18
Annelida			
Polychaeta			
Errantia			
Amphinomidae	1		2,12
Aphroditidae	5	Carnivores on polychaetes, e.g., terebellids and sabellids	2,12
Arabellidae: *Arabella, Drilonereis*	5	Juveniles parasites in poly-chaetes and echiurans; adults carnivores	2,12
Chrysopetalidae: *Paleanotus*	1	Carnivores	2,12
Dorvilleidae: *Dorvillea, Protodorvillea*	8	Carnivores	2,12
Eunicidae: *Eunice*	2	Carnivores on annelids, ostracods, copepods, and bivalves	2,12
Euphrosinidae	4		2,12

Taxon: Genera	Regional # of species	Trophic level	References
Glyceridae: *Glycera, Hemipodus*	8	Carnivores on polychaetes	2,12
Goniadidae: *Glycinde, Goniada*	6	Carnivores	2,12
Hesionidae: *Gyptis, Kefersteinia, Micropodarke, Ophiodromus*	4	Carnivores on annelids, cumaceans, and tanaids	2,12
Lumbrineridae: *Lumbrineris*	13	Herbivores on micro- and macro-algae; carnivores; detritivores	2,12
Nephtyidae: *Nephtys*	13	Carnivores on small benthic animals	2,12
Nereidae: *Cheilonereis, Micronereis, Nereis, Platynereis*	17	Herbivores on macroalgae	2,12
Onuphidae: *Diopatra, Onuphis*	7	Herbivores on macroalgae; scavenger on animal and plant tissue	2,12
Phyllodocidae: *Eteone, Eulalia, Hesionura, Phyllodoce*	27	Carnivores on polychaetes and other benthic animals; scavengers	2,12
Pilargidae: *Pilargis, Sigambra*	3	Carnivores or omnivores	2,12
Pisionidae: *Pisione*	1	Detritivores	2,12
Polynoidae: *Arctoroe, Eunoe, Halosydna, Harmothoe, Lepidasthenia, Tenonia*	29	Carnivores; *Harmothoe* on amphipods	2,12
Polyodontidae: *Peisidice*	1		2,12
Sigalionidae: *Pholoe, Thalenessa*	4	Carnivores on small invertebrates	2,12
Sphaerodoridae: *Sphaerodoropsis, Sphaerodorum*	3	Detritivores	2,12
Syllidae: *Autolytus, Eusyllis, Exogone, Odontosyllis, Pionosyllis, Sphaerosyllis, Streptosyllis, Syllides, Syllis, Trypanosyllis*	37	*Autolytus, Syllis, Trypanosyllis*, carnivores; other genera detritivores	2,12
Sedentaria			
Acrocirridae	1	Detritivores	17,12
Ampharetidae: *Ampharete, Asabellides*	18	Detritivores	17,12
Apistobranchidae: *Apistobranchus*	2	Detritivores	17,12
Arenicolidae: *Abarenicola, Arenicola, Branchiomaldane*	4	Detritivores	17,12

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Capitellidae: *Barantolla, Capitella, Decamastus, Mediomastus, Notomastus*	13	Detritivores	17,12
Chaetopteridae: *Mesochaetopterus, Phyllochaetopterus, Spiochaetopterus*	4	Suspension feeders and detritivores	17,12
Cirratulidae: *Caulleriella, Chaetozone, Cirratulus, Cirriformia, Dodecaceria, Tharyx*	17	Detritivores	17,12
Cossuridae	1		17,12
Ctenodriidae	2	Detritivores	17,12
Disomidae: *Trochochaeta*	1		17,12
Flabelligeridae: *Pherusa*	6	Detritivores	17,12
Magelonidae: *Magelona*	2	Detritivores	17,12
Maldanidae: *Axiothella, Euclymene, Maldane, Nicomache Notoproctus*	22	Detritivores	17,12
Opheliidae: *Ammotrypane, Armandia, Ophelia, Travisia*	10	Detritivores	17,12
Orbiniidae: *Naineris, Orbinia, Protoaricia, Scoloplos*	10	Detritivores	17,12
Oweniidae: *Myriochele, Owenia*	2	Detritivores	17,12
Paraonidae: *Aricidea, Paraonella*	11	Detritivores	17,12
Parergodrilidae: *Stygocapitella*	1		17,12
Pectinariidae: *Pectinaria*	3	Detritivores	17,12
Questidae: *Questa*	1		17,12
Sabellariidae: *Idanthyrsus, Sabellaria*	2	Suspension feeders on phytoplankton	17,12
Sabellidae: *Chone, Euchone, Eudistylia, Fabricia, Jasmineira, Manayunkia, Oriopsis, Potamilla, Sabella, Sabellastarte, Schizobranchia*	31	Suspension feeders on phytoplankton and small zooplankton	17,12
Scalebregmidae: *Scalibregma*	3	Detritivores	17,12
Serpulidae: *Pseudochitinopoma, Serpula, Spirorbis*	22	Suspension feeders on phytoplankton	17,12
Spionidae: *Laonice, Malacoceros, Polydora, Prionospio, Pygospio, Scolelepis, Spio, Spiophanes*	34	Detritivores; carnivores on zooplankton	17,12
Sternaspidae: *Sternaspis*	1	Detritivores	17,12
Terebellidae: *Eupolymnia, Neoamphitrite, Nicolea, Pista, Polycirrus, Proclea, Scionella, Thelepus*	31	Detritivores	17,12
Trichobranchidae	3		17,12

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Archiannelida			
Polygordidae: *Polygordius*	1	Detritivores	19,12
Protodrilidae: *Protodrilus, Protodriloides*	2	Detritivores	19,12
Nerillidae: *Nerilla*	3	Detritivores	19,12
Saccocirridae: *Saccocirrus*	1	Detritivores	19,12
Dinophilidae: *Trilobodrilus, Diurodrilus, Dinophilus*	3	Detritivores	19,12
Oligochaeta			
Enchytraeidae: *Enchytraeus, Lumbricillus*	8	Detritivores	32
Naididae: *Nais, Paranais*	?	Detritivores; carnivores on small mesozoans	32
Tubificidae: *Peloscolex, Monopylephorus, Limnodrilus*	?	Detritivores	32
Hirudinea	?	Carnivores, parasites on fishes, shrimp	32
Priapulida: *Priapulus caudatus*	1	Carnivores on polychaetes and priapulids	19,32, 3
Sipuncula: *Themiste, Pascolosoma, Golfingia*	4	Detritivores	19,18, 32
Echiura: *Echiurus, Arhychite, Nellobia*	3	Detritivores	19,32
Tardigrada: *Echiniscoides, Batillipes*	2	Herbivores (suctorial) on macroalgae	
Pycnogonida: *Achelia, Halosoma, Nymphon, Phoxichilidium, Pycnogonum*	20	Juveniles parasites on cnidarians; adults carnivores on hydroids, anemones, mussels	19,32
Arachnida			
Pseudoscorpionida: *Halobisium*	1	Carnivores on mites	32,19
Acari, Halacaridae	?	Herbivores (suctorial) on algae; carnivores	19,32
Crustacea			
Cladocera: *Podon, Evadne*	5	Carnivores on copepods	19,3
Ostracoda	42	Detritivores	19,3

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Copepoda			
Calanoida: *Calanus, Centropages, Acartia, Eucalanus, Paracalanus, Pseudocalanus, Microcalanus, Scaphocalanus, Metridia*	75	Suspension feeders on phytoplankton	19,3,9
Harpacticoida: *Harpacticus, Zaus, Tisbe, Oxyjulis, Porcellidium, Amonardia, Diosaccus, Amphiascopsis, Amphiascus, Dactylopodia, Parathalestris, Diarthrodes*	98+	Detritivores	19,3,9, 20
Cyclopoida: *Oncaea, Corycaeus, Clausidium, Oithona*	23+	Suspension feeders on phytoplankton; commensals with benthic invertebrates	19,9
Monstrilloida	4	Parasites in polychaetes	19
Caligoida	?	Ectoparasites on fish	19
Branchiura: *Argulus*	1	Ectoparasites on fish	19,3,32
Cirripedia			
Thoracica: *Pollicipes, Lepas, Chthamalus, Balanus*	21	Suspension feeders on phytoplankton and small zooplankton	19,3
Acrothoracica	1	Suspension feeders on phytoplankton	19,3
Rhizocephala	8	Parasites on decapod crustaceans	19,3
Leptostraca: *Nebalia*	2	Suspension feeders on detritus and microalgae	19,3
Mysidacea: *Mysis, Archaeomysis, Holmesiella, Neomysis, Acanthomysis*	30	Suspension feeders on microalgae and detritus	19,3
Cumacea: *Lamprops, Diastylopsis, Leptostylis, Diastylis, Eudorella, Leptocuma, Cumella*	31	Detritivores	19,3
Tanaidacea: *Pancolus, Anatanais, Leptochelia*	5	Detritivores; carnivores on small benthic animals	19,3
Isopoda			
Epicaridea			
Bopyridae: *Hemiarthrus, Pseudione, Argeia, Phyllodurus*	6	Parasites on shrimp and hermit crabs	19
Cryptoniscidae: *Cryptothir*	1	Parasites in barnacles	19
Entoniscidae: *Portunion*	1	Parasites in *Hemigrapsus*	19
Valvifera		Detritivores	
Idoteidae: *Edotea, Idotea, Synidotea*	16	Scavengers on macroalgae	19,18
Anthuridea		Detritivores	
Anthuridae: *Colanthura, Paranthura*	2		19

Taxon: Genera	Regional # of species	Trophic level	References
Flabellifera		Detritivores; parasites	
Aegidae: *Rocinela, Aega*	5	Ectoparasites on fishes	19,3
Cirolanidae: *Cirolana*	3	Scavengers on animal tissue	19,32
Cymothoidae: *Lironeca*	2		19
Limnoriidae: *Limnoria*	2	Boring "consumers" of kelp and wood	19,18
Sphaeromatidae: *Dynamenella, Exosphaeroma, Gnorimosphaeroma*	10	Scavengers on macroalgae	19,18
Microcerberidea		Detritivores	
Microcerberidae: *Microcerberus*	1		19
Asellota		Detritivores	
Jaeropsidae: *Jaeropsis*	3		19
Janiridae: *Janiropsis, Janiralata*	7		19
Munnidae: *Munna, Munnogonium*	6		19
Oniscoidea		Detritivores	
Armidillidiidae: *Armadillidium*	1		19
Ligiidae: *Ligia*	1	Scavengers on macroalgae	19,18
Oniscidae: *Alloniscus, Porcellia*	3		19
Scyphacidae: *Armadilloniscus, Detonella*	2		19
Amphipoda			
Hyperidea	?	Carnivores on planktonic cnidarians	19,3
Gammaridea			
Acanthonotozomatidae: *Panoploea*	1	Piercing/sucking mouthparts	34
Ampeliscidae: *Ampelisca, Byblis*	6	Detritivores	34
Amphilochidae: *Amphilochus*	2	Detritivores	34
Ampithoidae: *Ampithoe, Cymadusa*	6	Herbivores on macroalgae	34
Aoridae: *Aoroides*	1	Detritivores	34
Argissidae: *Argissa*	1	Detritivores	34
Atylidae: *Atylus*	3	Detritivores	34
Calliopiidae: *Calliopiella, Oligochinus*	2	Detritivores	34
Corophiidae: *Corophium, Ericthonius*	7	Detritivores	34
Dexaminidae: *Guernea, Polycheria*	2	Detritivores	34
Eusiridae: *Accedomoera, Paramoera, Pontogeneia*	11	Detritivores; carnivores	34

Taxon: Genera	Regional # of species	Trophic level	References
Gammaridae: *Anisogammarus*, *Ceradocus*, *Maera*, *Megaluropus*, *Melita*	9	Detritivores; *Anisogammarus* herbivores	34
Haustoriidae: *Eohaustorius*	2	Subsurface detritivores	34
Hyalidae: *Allorchestes*, *Hyale*, *Parallorchestes*	8	Detritivores; herbivores on macroalgae	34
Isaeidae: *Gammaropsis*, *Kermystheus*, *Photis*, *Podoceropsis*, *Protomedeia*	9	Suspension feeders on detritus; detritivores	34
Ischyroceridae: *Ischyrocerus*, *Jassa*, *Microjassa*, *Microjassalitotes*	5	Suspension feeders on detritus; herbivores; detritivores	34
Leucothoidae: *Leucothoe*	1	Detritivore (commensal in sponges)	34
Lysianassidae: *Anonyx*, *Hippomedon*, *Lepidepecreum*, *Orchomene*, *Pachynus*	10	Detritivores; carnivores	34
Nainidae: *Naina*	1	Detritivore (burrowing in *Alaria*)	34
Oedicerotidae: *Monoculodes*, *Synchelidium*, *Westwoodilla*	7	Detritivores	34
Phoxocephalidae: *Heterophoxus*, *Metaphoxus*, *Paraphoxus*,	17	Subsurface detritivores	34
Pleustidae: *Parapleustes*, *Pleusirus*, *Pleustes*, *Pleusymtes*	6	Detritivores	34
Podoceridae: *Dulichia*, *Podocerus*	2	Suspension feeders on detritus	34
Stenothoidae: *Metopa*, *Stenothoides*	2	Detritivores	34
Synopiidae: *Tiron*	1	Detritivores	34
Talitridae: *Orchestia*, *Orchestoidea*	3	Detritivores; scavengers on macroalgae	34,18
Caprellidea: *Caprella*, *Cerops*, *Deutella*, *Metacaprella*, *Tritella*	26	Herbivores on microalgae; detritivores; carnivores on harpacticoid copepods, amphipods, and ostracods	19,32, 18,8
Euphausiacea: *Euphausia*, *Thysanoessa*	13	Suspension feeders on phytoplankton	19,3,1
Decapoda			
Penaeidae: *Gennadas*	1	Carnivores on pelagic animals	19,3
Sergestidae: *Sergestes*	1	Carnivores on pelagic animals	19,3
Pasiphaeidae: *Pasiphaea*	1	Carnivores	
Oplophoridae: *Hymenodora*, *Notostomus*	2	Carnivores	19

Taxon: Genera	Regional # of species	Trophic level	References
Pandalidae: *Pandalopsis*, *Pandalus*	10	Carnivores	19
Crangonidae: *Argis*, *Paracrangon*, *Sclerocrangon*, *Crangon*	18	Carnivores	19
Alpheidae: *Betaeus*	2	Carnivores	19
Hippolytidae: *Hippolyte*, *Lebbeus*, *Eualus*, *Spirontocaris*, *Heptacarpus*	32	Carnivores	19
Axiidae: *Axiopsis*	1		19
Callianassidae: *Callianassa*, *Upogebia*	3	Detritivores by suspension feeding	19,18
Hippidae: *Emerita*	1	Suspension feeders	19
Galatheidae: *Munida*, *Munidopsis*	2	Carnivores	19
Porcellanidae: *Pachycheles*, *Petrolisthes*	4	Suspension feeders on detritus and plankton	19
Lithodidae: *Placetron*, *Hapalogaster*, *Oedignathus*, *Cryptolithodes*, *Phyllolithodes*, *Lopholithodes*	10	Carnivores, *Lopholithodes* on asteroids; *Hapalagoster* and *Oedignathus* suspension feeders on detritus and plankton	19
Diogenidae: *Paguristes*	2	Detritivores	19
Paguridae: *Elassochirus*, *Discorsopagurus*, *Labidochirus* *Orthopagurus*, *Pagurus*	25	Detritivores	19
Parapaguridae: *Parapagurus*	1	Detritivores	19
Majidae: *Chionoecetes*, *Chorilia*, *Hyas*, *Mimulus*, *Oregonia*, *Pugettia*, *Scyra*	10	Herbivores on macroalgae and eelgrass	19,8
Cancridae: *Cancer*, *Telmessus*	6	Carnivores; *C. magister* on bivalves	19,18
Xanthidae: *Lophopanopeus*	1		19
Pinnotheridae: *Fabia*, *Pinnixa*, *Pinnotheres*, *Scleroplax*	10	Parasites of bivalves, polychaetes	19,18
Grapsidae: *Hemigrapsus*, *Planes*	4	Scavengers on animal matter	19
Insecta			
Collembola: *Anurida*	1	Scavengers on macroalgae	32
Thysanura: *Neomachilis*	1		32
Diptera			
Tipulidae: *Limonia*	?	Larvae macroalgae herbivores	32
Chironomidae: *Paraclunio*	?	Larvae macroalgae herbivores	32

Taxon: Genera	Regional # of species	Trophic level	References
Dolichopodidae: *Aphrosylus*	?	Carnivores on chironomids	32
Helcomyzidae	?	Scavengers on macroalgae	32
Coleoptera			
Staphylinidae: *Diaulota*, *Emplenota*, *Liparocephalus*, *Pontomalota*	?	Carnivores on dipteran larvae	32
Salpingidae: *Aegialites*	?		32
Phoronida: *Phoronis*, *Phoronopsis*	3	Suspension feeders on phytoplankton	19,3
Bryozoa (Ectoprocta)			
Ctenostomata: *Alcyonidium*, *Bowerbankia*, *Buskia*, *Clavopora*, *Flustrella*, *Nolella*, *Triticella*	7+	Suspension feeders on phytoplankton	19,3
Cyclostomata: *Bicrisia*, *Crisia*, *Crisidia*, *Diaperoecia*, *Diplosolen*, *Discocytis*, *Disporella*, *Filicrisia*, *Filifascigera*, *Heteropora*, *Idmonea*, *Lichenipora*, *Oncousoecia*, *Plagioecia*, *Proboscina*, *Stomatopora*, *Tubulipora*	19+	Suspension feeders on phytoplankton	19,3
Cheilostomata: *Aetea*, *Alderina*, *Arthropoma*, *Bugula*, *Caberea*, *Caulibugula*, *Cauloramplius*, *Cellaria*, *Cheilopora*, *Codonellina*, *Colletosia*, *Conopeum*, *Copidozoum*, *Corynoporella*, *Costazia*, *Cribrilina*, *Dendrobeania*, *Doryporella*, *Electra*, *Ellisina*, *Eurystomella*, *Fenestratulina*, *Hincksina*, *Hippodiplosia*, *Hippomonavella*, *Hippothoa*, *Holoporella*, *Lagenipora*, *Lyrula*, *Membranipora*, *Micropora*, *Microporella*, *Microporina*, *Mucronella*, *Myriozoum*, *Parasmittina*, *Phidolopora*, *Porella*, *Puellina*, *Reginella*, *Rhamphostomella*, *Schizomavella*, *Schizoporella*, *Scrupocellaria*, *Smittina*, *Stephanosella*, *Tegella*, *Terminoflustra*, *Tricellaria*, *Trypostega*, *Umbonula*	55+	Suspension feeders on phytoplankton	19,3
Brachiopoda: *Hemithyris*, *Laqueus*, *Terebratalia*, *Terebratulina*	4	Suspension feeders on phytoplankton	19,3
Echinodermata			
Crinoidea: *Florometra*	1	Detritivores	19,3

Taxon: Genera	Regional # of species	Trophic level	References
Ophiuroidea: *Amphiodia, Amphipholis, Diamphiodia, Gorgonocephalus, Ophiopholis, Ophiura, Unioplus*	25	Detritivores	19,3
Asteroidea: *Crossaster, Dermasterias, Evasterias, Henricia, Hippasteria, Leptasterias, Luidia, Mediaster, Orthasterias, Pisaster, Pycnopodia, Solaster*	19	*Crossaster* carnivores on *Ptilosarcus* and opisthobranchs; *Dermasterias* on *Ptilosarcus*, actinians, sponge and holothurians; *Hippasteria* on *Ptilosarcus*; *Leptasterias* on barnacles, limpets, *Lacuna*, *Littorina*, chitons, holothurians; *Mediaster* on *Ptilosarcus*, algae, detritivore; *Pisaster* on *Mytilus*, barnacles, limpets, chitons; *Pycnopodia* on large bivalves, sea urchins; *Solaster dawsoni* on asteroids; *Solaster endeca* and *S. stimpsoni* on holothurians	19,5, 18,26, 23,24, 25,22
Echinoidea: *Dendraster, Strongylocentrotus*	7	*Dendraster* detritivores; *Strongylocentrotus* herbivores on macroalgae	19,3
Holothuroidea: *Cucumaria, Eupentacta, Leptosynapta, Molpadia, Parastichopus, Psolus, Thyone*	13	*Leptosynapta* and *Parastichopus* detritivores; rest suspension feeders on detritus and phytoplankton	19,3, 11
Chaetognatha: *Eukrohnia, Sagitta*	4	Carnivores on zooplankton and small fish	19,3
Hemichordata: *Saccoglossus*	1	Detritivores	19,3
Chordata-Urochordata Larvacea: *Fritillaria, Oikopleura*	3	Suspension feeders on phytoplankton	19,3

Taxon: Genera	Regional # of species	Trophic level	References
Ascidiacea: *Aplidium, Archidistoma, Ascidia, Boltenia, Chelyosoma, Ciona, Clavelina, Cnemidocarpa, Corella, Cystodytes, Diplosoma, Distaplia, Halocynthia, Metandrocarpa, Molgula, Perophora, Pycnoclavella, Pyura, Ritterella, Styela, Synoicum, Trididemnum*	42	Suspension feeders on phytoplankton	19,3
Thaliacea			
Salpidae	?	Suspension feeders on phytoplankton	19,3
Doliolidae	?	Suspension feeders on phytoplankton	19,3

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APPENDIX B: FISHES

Numerical classification of the nearshore fish collection data from northern Puget Sound and the Strait of Juan de Fuca indicated that 64 species composed the principal components of the region's nearshore fish communities (Table B-1). Sixteen assemblages were distinguished in this analysis, including two neritic, eleven shallow sublittoral, two littoral, and one (rocky) sublittoral assemblage. Two species, copper rockfish and tidepool sculpin, occurred in more than one assemblage.

Identification of functional feeding groups based on the DOE and MESA food habits data based and pertinent literature, summarized in the following species accounts section, indicated that facultative epibenthic planktivores and benthivores, 26 and 16 species, respectively, predominated (Table B-1).* Obligate epibenthic planktivores and facultative pelagic planktivores were secondary in importance.

In the following species accounts of food habits, unless cited otherwise, references to data collected in northern Puget Sound resulted from the DOE baseline studies (Miller, et al., 1977; Moulton, 1977) and in the Strait of Juan de Fuca, under the auspices of NOAA's Puget Sound MESA program (Simenstad et al. 1977; Cross, et al., 1978).

Species Accounts

Spiny Dogfish

Spiny dogfish examined during DOE studies in northern Puget Sound had a high percentage (71%) of the stomach contents digested and unidentifiable. Epibenthic gammarid amphipods and shrimp and benthic gastropods dominated the diet numerically, while Pacific sand lance (Ammodytes hexapterus) contributed 95% of the total consumed (identifiable) biomass. The one spiny dogfish from the eastern region sampled by WWSG contained four gammarid amphipods, one polychaete annelid, and one turbellarian.

The most comprehensive compilation of food habits data for spiny dogfish in northern Puget Sound was that reported by Jones and Geen (1977) for British Columbia waters, principally the Strait of Georgia. Analysis of almost 15,000 stomachs over 30 years indicated that Pacific herring (Clupea harengus pallasi) euphausiids, unidentified eggs, and caridean crustaceans were the principal prey organisms for all life history stages combined (Table B-2).

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*See Methods section in body of report for definition of terms describing feeding types.

Table B-1. Representative nearshore fish assemblages of northern Puget Sound and the Strait of Juan de Fuca and functional feeding groups of component species. See methods section for assemblage determinations and definition of feeding groups; F = facultative feeder, O = obligate feeder.

			Functional Feeding Group				
Zone	Species Assemblage	Component Species	Pelagic Planktivore	Epibenthic Planktivore	Epibenthic Benthivore	Meiobenthic Benthivore	Omnivore
Neritic	1	Pacific herring, *Clupea harengus pallasi**	O				
		Threespine stickleback, *Gasterosteus aculeatus*		O			
		Pacific sand lance, *Ammodytes hexapterus*	O				
		Pink salmon, *Oncorhynchus gorbuscha**	F				
		Coho salmon, *O. kisutch**		F			
		Chinook salmon, *O. tshawytscha**		F			
		Tadpole sculpin, *Psychrolutes paradoxsus*		O			
	2	Surf smelt, *Hypomesus pretiosus*	F				
		Longfin smelt, *Spirinchus thaleichthys*		F			
		Northern anchovy, *Engraulis mordax*	F?				
		Soft sculpin *Gilbertidia sigalutes*	O?				
Shallow Sublittoral	3	Rock sole, *Lepidopsetta bilineata*			F		
		C-O sole, *Pleuronichthys coenosus*			F		
		English sole, *Parophrys vetulus**		F			
		Shiner perch, *Cymatogaster aggregata*		F			
		Pile perch, *Rhacochilus vacca*		F			

Table B-1 (continued).

			Functional Feeding Group				
Zone	Species Assemblage	Component Species	Pelagic Planktivore	Epibenthic Planktivore	Epibenthic Benthivore	Meiobenthic Benthivore	Omnivore
	4	Pacific tomcod, *Microgadus proximus**		F			
		Sturgeon poacher, *Agonus acipenserinus*			F		
		Roughback sculpin, *Chitonotis pugetensis*			F		
	5	Speckled sanddab, *Citharichthys stigmaeus*		F			
		Pacific sanddab, *C. sordidus*		F			
	6	Staghorn sculpin, *Leptocottus armatus*			F		
		Starry flounder, *Platichthys stallatus*			F		
		Snake prickleback, *Lumpenus sagitta*				F	
		Tidepool sculpin, *Oligocottus maculosus*		F			
	7	Sand sole, *Psettichthys melanostictus**			F		
		Redtail surfperch, *Amphisticus frenatus*		O			
	8	Chum salmon, *Oncorhynchus keta**		O			
	9	Penpoint gunnel, *Apodichthys flavidus*		F			
		Cresent gunnel, *Pholis laeta*		F			
		Silverspotted sculpin, *Blepsias cirrhosus*		F			
		Whitespotted greenling, *Hexagrammos stelleri*			F		
		Tubenose poacher, *Pallasina barbata*		O			

Table B-1 (continued).

			Functional Feeding Group				
Zone	Species Assemblage	Component Species	Pelagic Planktivore	Epibenthic Planktivore	Epibenthic Benthivore	Meiobenthic Benthivore	Omnivore
	10	Padded sculpin, *Artedius fenestralis*			F		
		Buffalo sculpin, *Enophrys bison*					F
		Great sculpin, *Myoxocephalus polyacanthocephalus*		F			
		Sharpnose sculpin, *Clinocottus acuticeps*		F			
	11	Tube-snout, *Aulorhynchus flavidus*	F				
		Bay pipefish, *Syngnathus griseolineatus*		O			
		Cabezon, *Scorpaenichthys marmoratus**			O		
	12	Copper rockfish, *Sebastes caurinus**		F			
		Smoothhead sculpin, *Artedins lateralis*		O			
		Manacled sculpin, *Synchirus gilli*		O?			
	13	Walleye pollock, *Theragra chalcogramma*	F				
		Spiny lumpsucker, *Eumicrotremus orbis*		O			
		Spiny dogfish, *Squalus acanthias*			F		
		Ratfish, *Hydrolagus colliei*			F		
Littoral	14	High cockscomb, *Anoplarchus purpurencens*			F		
		Northern clingfish, *Gobiesox maeandricus*			F		
		Rosylip sculpin, *Ascelichthys rhodorus*		F			
		Ringtail snailfish, *Liparis rutteri*		F?			

Table B-1 (continued).

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			Functional Feeding Group				
Zone	Species Assemblage	Component Species	Pelagic Planktivore	Epibenthic Planktivore	Epibenthic Benthivore	Meiobenthic Benthivore	Omnivore
	15	Black prickleback, *Xiphister atropurpureus*		F			
		Tidepool sculpin, *Oligocottus maculosus*		F			
		Mosshead sculpin, *Clinocottus globiceps*			F		
		Saddleback sculpin, *Oligocottus rimensis*		0			
		Fluffy sculpin, *Oligocottus snyderi*		F			
		Rock prickleback, *Xiphister mucosus*			F?		
		Calico sculpin, *Clinocottus embryum*		F			
		Tidepool snailfish *Liparis florae*		F			
Rocky/ Kelp Bed	16	Yellowtail rockfish, *Sebastes flavidus*	F				
		Black rockfish, *S. melanops*	F				
		Copper rockfish, *S. caurinus*		F			
		Puget Sound rockfish, *S. emphaeus*	F				
		Kelp greenling, *Hexagrammos decagrammus*			F		
		Lingcod, *Ophiodon elongatus*			0		
		Longfin sculpin, *Jordania zonope*		F			
		Striped seaperch, *Embiotoca lateralis*		F			
Total (w/o duplication)			8 F/3 0	26 F/10 0	16 F/2 0	1 F	1 F

*Predominantly juveniles.

Table B-2. Prey composition of spiny dogfish reported by Jones and Geen (1977) (n = 14,796).

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PREDATOR  8713010201 - SQUALUS ACANTHIAS                         (SPINY DOGFISH


                INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                  FROM FILE IDENT. REF 13. STATION TOTAL
                ********************************************

                                    FREQ   NUM.   GRAV.  PREY      PERCENT
           PREY ITEM                OCCUR  COMP.  COMP.  I.R.I.   TOTAL IRI
 ------------------------------     -----  -----  -----  ------   ---------

 CLUPEA HARENGUS PALLASI            16.33  21.84
 EUPHAUSIACEA                       15.68  16.63
 UNIDENTIFIED EGG                   10.88   9.65
 PLEOCYEMATA-CARIDEA                 9.89   8.03
 DECAPODA-BRACHYURA                  3.72   7.09
 THALEICHTHYS PACIFICUS              3.23   5.53
 MERLUCCIUS PRODUCTUS                2.68   6.79
 PLEUROBRANCHIA SP.                  2.34   2.40
 LOLIGO SP.                          2.14   1.71
 OCTOPUS DOFLEINI                    2.14   3.05
 HYDROLAGUS COLLIEI                  1.65   2.68
 PLEURONECTIDAE                      1.64   5.89
 POLYCHAETA                          1.63    .29
 AMMODYTES HEXAPTERUS                1.60   1.68
 EMBIOTOCIDAE                        1.58    .39
 SCORPAENIDAE                        1.48    .60
 AMPHIPODA                           1.47    .60
 SCAPHOPODA                           .97   1.17
 GADUS MACROCEPHALUS                  .69   1.35

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                  .11    .00               .00
      SHANNON-WEINER DIVERSITY                3.46    .00               .00
      EVENNESS INDEX                           .81    .00               .00
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Ratfish

A nocturnal predator in the nearshore demersal fish assemblage in exposed gravel-cobble habitats in the San Juan Islands, the ratfish illustrated one of the most diverse diets examined. Eight ratfish fed on an array of brachyuran crabs (*Cancer magister*, *C. oregonensis*, *Pugettia gracilis*, and *Telmessus cheiragonus*), valviferan (*Synidotea* sp.) and flabelliferan isopod gammarid amphipods (*Paraphoxus spinosa*, *Esiroides* sp., *Pontogeneia* sp., *Photis californica*, *Photis* sp., Lyssiansidae sp., *Aorides* sp.), gastropods, other diverse peracaridan crustaceans (*Hippolyte clarki*, *Heptacarpus stimpsoni*, *Parapaguridae*, and *Paguristes* sp.), hyperiid amphipods, oniscoiden isopods, polychaetes, bivalves, fish, tanaidaceans, and amphineurans. Composition of the prey by weight was dominated by unidentifiable fishes (54%) and brachyuran crabs (13%).

Pacific Herring

Juvenile Pacific herring constitute the predominant species in North Puget Sound's neritic fish assemblage (Fresh 1979). The specimens examined indicated a low mean fullness factor, high stages of digestion, and the fifth highest percentage of empty stomachs; this was perhaps due to high digestive and gastric evacuation rates and because these fish, which may be predominantly diurnal-feeding fish, were generally collected at night.

Calanoid copepods dominated the overall diet composition by frequency of occurrence, percentage abundance, and percentage biomass in fish collected in northern Puget Sound (Fig. B-1). Harpacticoid and cyclopoid copepods, hyperiid amphipods, barnacle nauplius and cypris stages, and crab zoea were less important while camaceans, gammarid amphipods, and mysids contributed significant percentages of the total biomass of prey organisms. In addition to the prey indicated in Fig. B-1, crab megalops, euphausiids, crustacean eggs, fish larvae, and diverse crustacean larvae contributed to the total diet.

Juvenile Pacific herring were also captured during beach seine collections along the eastern shoreline, primarily along the northeast and south sides of Guemes Island, and at the Cherry Point and Birch Bay sites. These fish fed principally on shallow sublittoral epibenthic organisms such as harpacticoid copepods which composed 82 percent of the total IRI; shrimp larvae and other pelagic organisms, accounted for only 13.5 percent (Fig. B-2). Other epibenthic organisms--gammarid amphipods, oniscoidean and valviferan isopods, shrimp and bivalves--made only incidental contributions to the total IRI.

The diet composition from several sites and sampling periods indicated major differences in food habits between habitats and seasons. A series of samples obtained from three of the northeastern Puget Sound sites--Birch Bay, Cherry Point, and Padilla Bay--indicated that different planktonic organisms were the principal dietary components at the different sites, i.e., calanoid copepods in Padilla Bay, mysids in Birch Bay, and barnacle (cypris) nauplii at Cherry Point.

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INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD, STATION ALSTA
          PREDATOR  8747010201 - CLUPEA HARENGUS PALLASI
        (PACIFIC HERRING      )  ADJUSTED SAMPLE SIZE = 115
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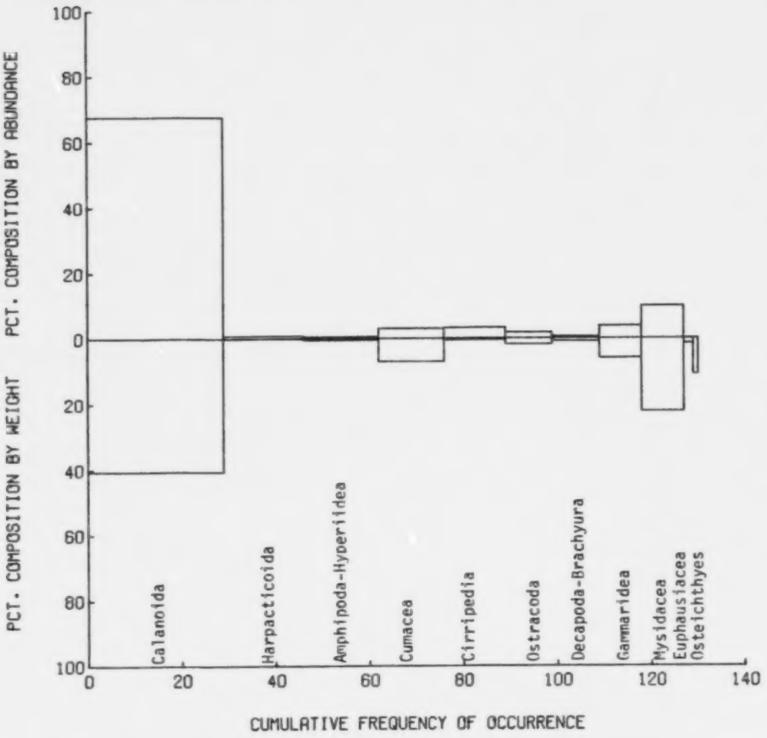

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                                     FREQ   NUM.   GRAV.   PREY     PERCENT
         PREY ITEM                   OCCUR  COMP.  COMP.   I.R.I.   TOTAL IRI
 ----------------------------        -----  -----  -----   ------   ---------

  CALANOIDA                          29.00  67.63  40.50   3135.8     83.50
  HARPACTICOIDA                      17.00    .78    .04     13.9       .30
  AMPHIPODA-HYPERIIDEA               16.00    .54    .48     17.0       .50
  CUMACEA                            14.00   2.98   7.02    140.0      3.70
  CIRRIPEDIA                         13.00   3.22    .45     11.0       .30
  OSTRACODA                          10.00   1.73   1.80     35.3       .90
  DECAPODA-BRACHYURA                 10.00    .53    .85     13.8       .30
  GAMMARIDEA                          9.00   3.74   5.91     86.8      2.30
  MYSIDACEA                           9.00   9.82  22.24    288.5      7.70
  EUPHAUSIACEA                        2.00    .04   1.45      3.0       .10
  OSTEICHTHYES                        1.00    .06  10.80     10.9       .30

    PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
    COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
    (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                .47    .23                  .71
      SHANNON-WEINER DIVERSITY              1.45   2.20                 1.01
      EVENNESS INDEX                         .42    .63                  .29
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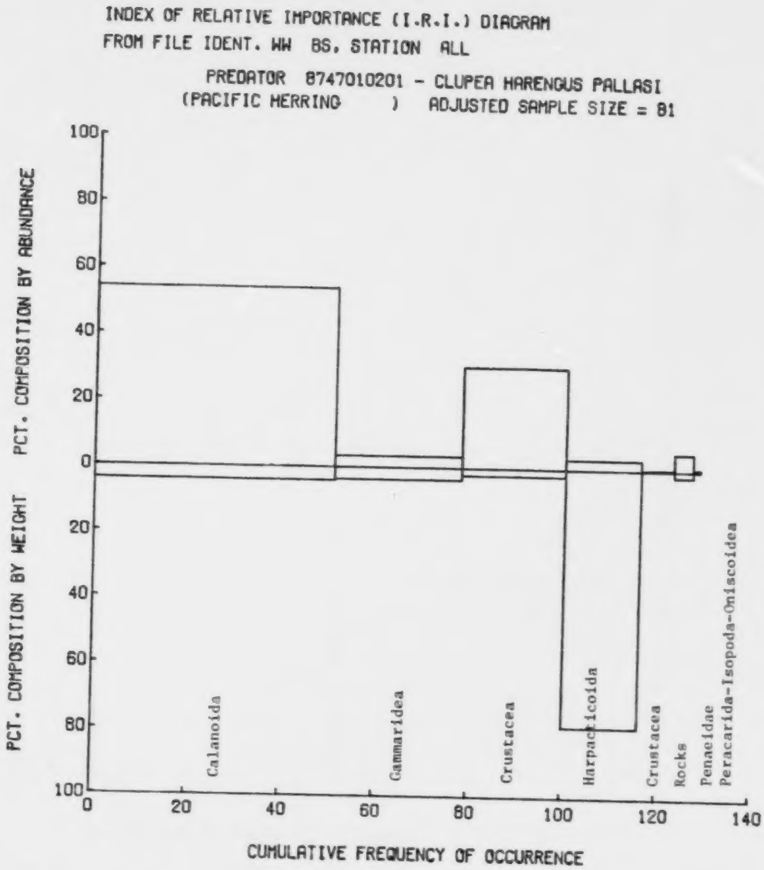
Fig. B-1. IRI prey spectrum of juvenile Pacific herring in neritic waters of northern Puget Sound.



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                                   FREQ   NUM.    GRAV.   PREY     PERCENT
         PREY ITEM                 OCCUR  COMP.   COMP.   I.R.I.   TOTAL IRI
  ----------------------------     -----  -----   -----   ------   ---------

  CALANOIDA                        51.00  54.22    4.11   2974.9     56.80
  GAMMARIDEA                       27.00   3.49    3.75    195.5      3.70
  CRUSTACEA                        22.00  30.62    2.25    723.1     13.80
  HARPACTICOIDA                    16.00   3.09   78.46   1304.8     25.00
  CRUSTACEA                         7.00    .35     .00      2.5       .00
  ROCK                              4.00   5.19    1.95     28.6       .50
  PENAEIDAE                         1.00    .45    3.91      4.4       .00
  PERACARIDA-ISOPODA-ONISCOIDEA     1.00    .42    2.74      3.2       .00

    PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
    COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
    (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX              .39     .62                .41
      SHANNON-WEINER DIVERSITY            1.64    1.20               1.57
      EVENNESS INDEX                       .55     .43                .68
```

Fig. B-2. IRI prey spectrum of juvenile Pacific herring in shallow sublittoral waters along the eastern shoreline of northern Puget Sound.

Pacific herring were also the most commonly encountered neritic fish throughout the Strait of Juan de Fuca occurring at all townet sites as post-larvae and juveniles through midwinter. Although fish larvae (primarily Pacific herring and Pacific sand lance) accounted for over 80% of the prey biomass, calanoid copepods were the most common prey both in occurrence and numerical composition and thus formed over 96% of the total IRI (Fig. B-3).

Extensive data on prey composition of larval and post-larval Pacific herring caught in the Strait of Georgia's surface waters (Barraclough 1967a, b & c; Barraclough & Fulton 1967, 1968; Robinson et al. 1968 a & b; Barraclough et al. 1968; Robinson 1969) indicated that Calanus plumchrus was the predominant calanoid copepod consumed; Pseudocalanus minutus, Acartia sp., the euphausiid, Thysanoessa longipes, and the hyperiid amphipod, Parathemisto pacifica were less important zooplankters and larval fish (Thaleichthys pacificus, Leuroglossus stilbius, Merluccius productus) appeared often in the diet but seldom in abundance. Pacific herring from the nearshore environs of the east and south coasts of Kodiak Island also have been shown to almost exclusively (>99% by numbers and biomass) feed upon calanoid copepods (Harris and Hartt 1977).

Northern Anchovy

Northern anchovies were commonly captured in spring and early summer in the northeastern study areas (Padilla Bay, Birch Bay, and Cherry Point) during the DOE baseline studies). As with herring, the state of the anchovy stomach samples indicated a high rate of digestion with a significant proportion of unidentifiable material in the total stomach contents sample (65.4 percent)

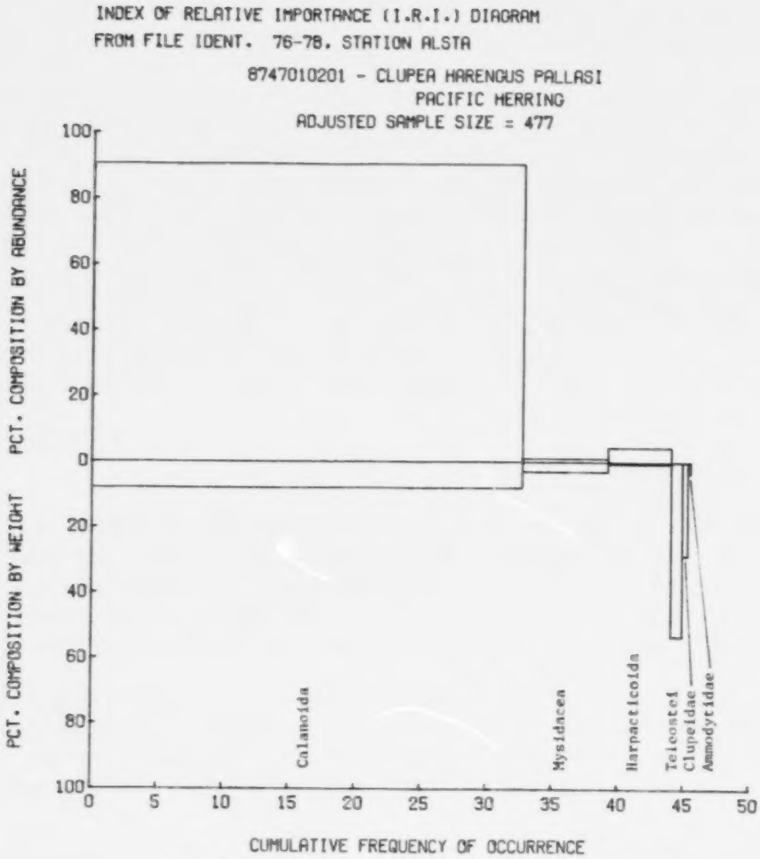
The identifiable organisms (Fig. B-4) indicated rather unselective planktonic food habits. Fish (juvenile rockfish) and fish larvae (Clupeidae), harpacticoid and calanoid copepods, crab and barnacle larvae, and insects, in descending order, composed the prey organisms with the highest IRI values.

Pink Salmon (Juveniles)

Pink salmon spawn cyclically in odd years in this region. Thus, the juveniles are present in abundance only during even-numbered years. Juvenile pink salmon were present in the largest numbers in the neritic waters of northern Puget Sound from June-August and were most evident in the sand/eel-grass habitats. In this region they preyed on a diverse assortment of epi-benthic and neritic plankton, with calanoid copepods providing the highest percentage of the total IRI, and harpacticoid copepods, gammarid amphipods, barnacle larvae, and cumaceans contributing lower, but fairly equal proportions (Fig. B-5).

Larvaceans and calanoid copepods were the only important preh organisms composing the overall prey spectrum of juvenile pink salmon caught in the Strait of Juan de Fuca (Fig. B-6).

Amphipods (Orchomenella sp., Calliopius sp., Parathemisto pacifica), calanoid copepods (Calanus pacificus, Eucalanus bungi bungi, Acartia sp., Pseudocalanus minutus), larvaceans and a diverse array of insects (principally families of Diptera) composed the majority of the prey consumed by juvenile pink salmon collected in the Strait of Georgia (Barraclough 1967a, b & c;



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                                 FREQ   NUM.   GRAV.   PREY     PERCENT
        PREY ITEM                OCCUR  COMP.  COMP.   I.R.I.   TOTAL IRI
----------------------------     -----  -----  -----   ------   ---------

CALANOIDA                        32.70  90.53   8.00   3222.3     96.40
MYSIDACEA                         6.50   1.09   2.98     26.5       .79
HARPACTICOIDA                     4.82   4.49    .54     24.2       .72
TELEOSTEI                          .84    .02  53.43     44.8      1.34
CLUPEIDAE                          .42    .03  28.66     12.0       .36
AMMODYTIDAE                        .21    .00   3.41       .7       .02

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

       PERCENT DOMINANCE INDEX             .82    .38                .93
       SHANNON-WEINER DIVERSITY            .72   1.90                .31
       EVENNESS INDEX                      .15    .39                .06
```
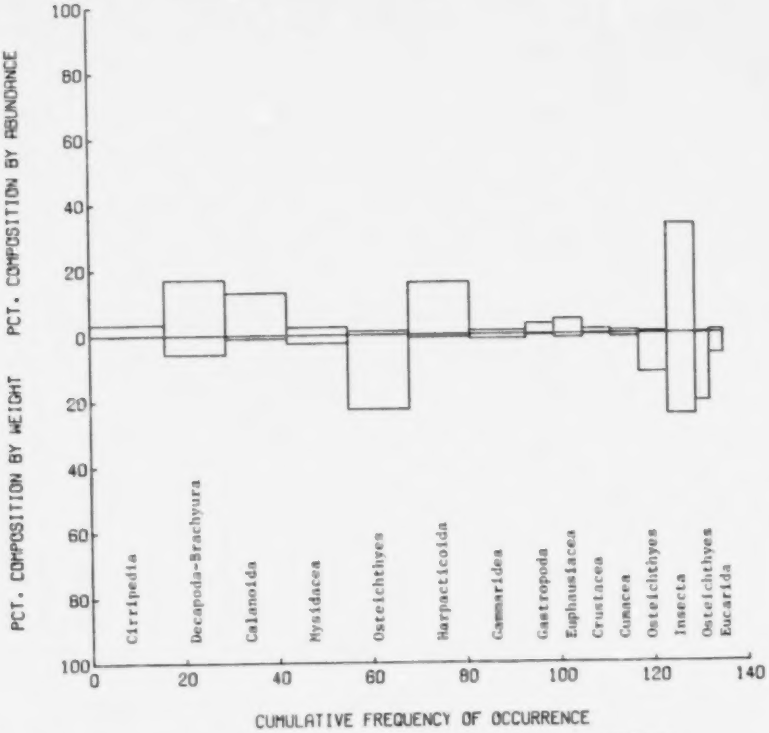

Fig, B-3. IRI prey spectrum of juvenile Pacific herring in neritic waters of Strait of Juan de Fuca.

Reproduced from best available copy.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD, STATION ALSTA
PREDATOR 8747020101 - ENGRAULIS MORDAX
(NORTHERN ANCHOVY) ADJUSTED SAMPLE SIZE = 31



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CIRRIPEDIA	16.00	3.31	.00	53.0	4.30
DECAPODA-BRACHYURA	13.00	17.00	5.64	294.3	23.80
CALANOIDA	13.00	13.02	1.03	182.6	14.80
MYSIDACEA	13.00	2.43	2.46	17.9	1.40
OSTEICHTHYES	13.00	1.10	22.67	309.0	25.00
HARPACTICOIDA	13.00	15.89	.82	217.2	17.50
GAMMARIDEA	12.00	1.10	1.34	29.3	2.40
GASTROPODA	6.00	3.09	.21	19.8	1.60
EUPHAUSIACEA	6.00	4.42	1.13	33.3	2.70
CRUSTACEA	6.00	1.32	.10	8.5	.70
CUMACEA	6.00	.88	1.03	11.5	.90
OSTEICHTHYES	6.00	.44	11.79	73.4	5.90
INSECTA	6.00	33.11	24.62	63.7	5.10
OSTEICHTHYES	3.00	.22	20.51	62.2	5.00
EUCARIDA	3.00	.83	6.15	21.1	1.70

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.19	.18	.18
SHANNON-WEINER DIVERSITY	2.81	2.81	3.37
EVENNESS INDEX	.72	.74	.86

Fig. B-4. IRI prey spectrum of northern anchovy in neritic waters of northern Puget Sound.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
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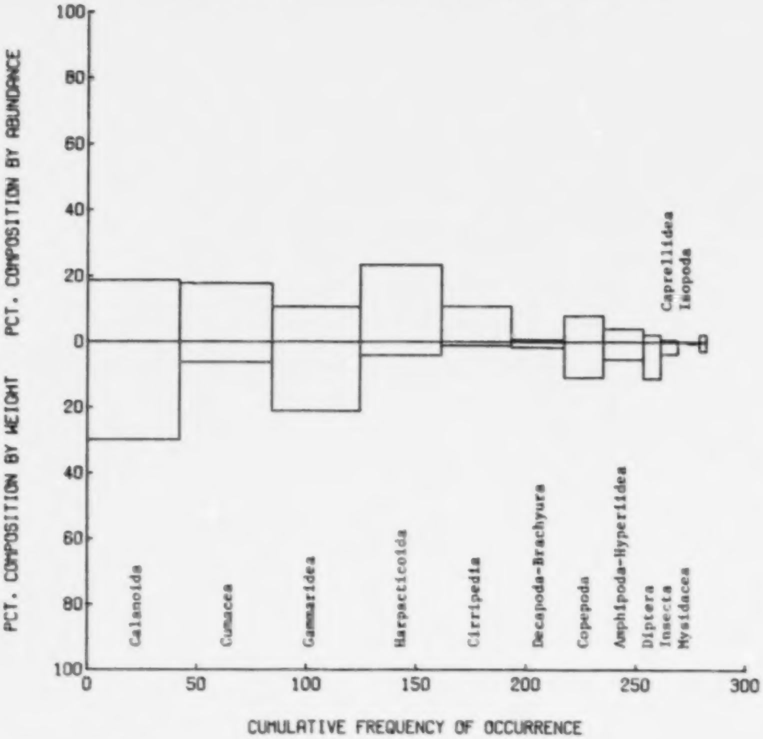
PREDATOR 8755010201 - ONCORHYNCHUS GORBUSCHA
(PINK SALMON) ADJUSTED SAMPLE SIZE = 38



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CALANOIDA	42.00	18.65	29.96	2041.6	31.80
CUMACEA	42.00	17.72	6.22	1005.5	15.70
GAMMARIDEA	40.00	10.61	21.02	1265.2	19.70
HARPACTICOIDA	37.00	23.33	4.07	1013.8	15.80
CIRRIPEDIA	32.00	10.73	1.12	379.2	5.90
DECAPODA-BRACHYURA	24.00	.61	1.68	55.0	.90
COPEPODA	18.00	7.92	10.77	336.4	5.20
AMPHIPODA-HYPERIIDEA	18.00	3.93	5.31	166.3	2.60
DIPTERA	8.00	2.23	11.05	106.2	1.70
INSECTA	8.00	.58	3.59	33.4	.50
MYSIDACEA	5.00	.05	.00	.3	.10
CAPRELLIDEA	5.00	.08	.40	2.4	.10
ISOPODA	3.00	2.21	2.79	15.0	.20

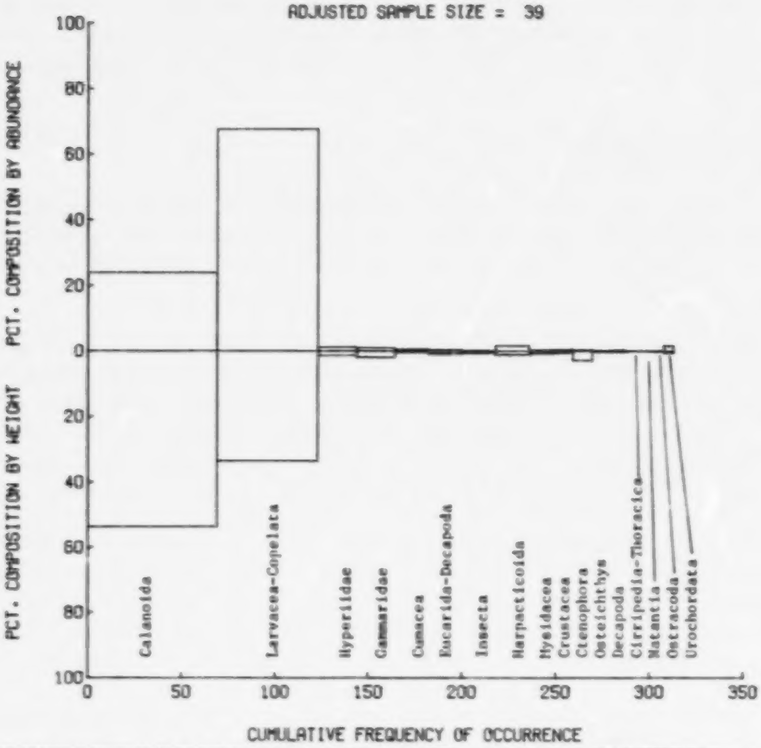
PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

		NUM. COMP.	GRAV. COMP.		PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX		.15	.17		.20
SHANNON-WEINER DIVERSITY		2.89	2.87		2.66
EVENNESS INDEX		.79	.80		.72

Fig. B-5. IRI prey spectrum of juvenile pink salmon in neritic waters of northern Puget Sound.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78. STATION ALSTA

8755010201 - ONCORHYNCHUS GORBUSCHA
PINK SALMON
ADJUSTED SAMPLE SIZE = 39



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                              FREQ   NUM.   GRAV.   PREY    PERCENT
         PREY ITEM            OCCUR  COMP.  COMP.   I.R.I.  TOTAL IRI
 ---------------------------  -----  -----  -----  ------  ---------

 CALANOIDA                    69.23  23.86  53.78  5375.0    48.32
 LARVACEA-COPELATA            51.85  67.69  33.55  5451.0    49.00
 HYPERIIDAE                   20.51   1.18   1.42    53.4      .48
 GAMMARIDAE                   20.51   1.01   1.94    60.5      .54
 CUMACEA                      17.95    .63    .32    17.2      .15
 EUCARIDA-DECAPODA            17.95    .39    .91    23.3      .21
 INSECTA                      17.95    .19    .50    12.5      .11
 HARPACTICOIDA                17.95   1.70   1.13    50.7      .46
 MYSIDACEA                    12.82    .35    .80    14.8      .13
 CRUSTACEA                    10.26    .34    .56     9.2      .09
 CTENOPHORA                   10.26    .26   2.94    32.8      .29
 OSTEICHTHYS                  10.26    .11    .27     3.8      .03
 DECAPODA                      7.69    .25    .16     3.1      .03
 CIRRIPEDIA-THORACICA          7.69    .03    .01      .3      .00
 NATANTIA                      7.69    .03    .02      .4      .00
 OSTRACODA                     5.13    .02    .11      .7      .01
 UROCHORDATA                   5.13   1.51    .59    10.8      .10

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX           .52    .40                .47
      SHANNON-WEINER DIVERSITY         1.46   1.82               1.24
      EVENNESS INDEX                    .33    .41                .28
```

Fig. B-6. IRI prey spectrum of juvenile pink salmon in neritic waters of the Strait of Juan de Fuca.

Barraclough & Fulton 1967; Robinson et al. 1968 a & b; Barraclough and Fulton 1968; Barraclough et al. 1968; Robinson 1969).

Harpacticoid copepods dominated the prey spectra of juvenile pink salmon captured in nearshore habitats at Kodiak Island while calanoid copepods, barnacle larvae, crustacean nauplii, harpacticoid copepods and fish eggs were prevalent in the diet of those fish captured in pelagic habitats (Harris and Hartt 1977).

Chum Salmon (Juveniles)

Juvenile chum salmon occurred throughout the north Puget Sound DOE study area from May-August, principally in the neritic fish assemblages where they were most common in collections from Lummi Bay, Burrows Island, and South Beach.

Chum juveniles had a less diverse overall prey spectrum than the pink juveniles. Calanoid copepods completely dominated the total IRI (80 percent), with hyperiid amphipods being second in importance (12 percent). Harpacticoid copepods, gammarid amphipods, cumaceans, and euphausiids were other less important prey items. This prey spectrum indicates that juvenile chums had a more pelagic feeding behavior than juvenile pinks, although epibenthic organisms also were important prey in the chum diet, especially when they frequented shallow sublittoral habitats (this occurred generally when the juvenile are ≤ 55 mm in length). Thus, when the combined prey compositions of juvenile chum salmon caught in beach seine collections (Fig. B-7) were compared with those collected by townet (Fig. B-8), it was apparent that the (earlier, smaller) chums frequenting the shallow sublittoral environment fed predominantly upon epibenthic organisms--harpacticoid copepods, gammarid amphipods, and oniscoidean isopods--while neritic (later, larger) chums utilized pelagic organisms--calanoid copepods and hyperiid amphipods.

Juvenile chum salmon were captured in high numbers during spring beach seine collections along the Strait of Juan de Fuca, especially at Kydaka Beach, Beckett Point, and Alexander's Beach, and also were in townet collections at Beckett Point. Main prey of chum fry included epibenthic organisms (harpacticoid copepods and gammarid amphipods) and pelagic organisms (calanoid copepods and fish larvae) (Fig. B-9).

This transition in feeding behavior from epibenthic to neritic organisms appears to be representative of most regions of Puget Sound, including Hood Canal (Feller and Kaczynski 1975; Simenstad and Kinney 1978), Nisqually Reach (Feller and Kaczynski 1975; Fresh, et al., 1978), east central Puget Sound (Feller 1977), and in the Strait of Georgia (Healy, et al., 1976). Detailed analysis of prey consumed in neritic waters (Barraclough 1967a,b,c; Barraclough and Fulton 1967, 1968; Robinson, et al., 1968a,b; Barraclough, et al., 1968; Robinson 1969; Simenstad and Kinney, unpubl. data) suggests that juvenile chums predominantly utilize large calanoids (e.g., *Calanus pacificus*, *C. plumchrus*), which are the principal components of diel-migrating deep-water community, rather than the smaller but more abundant calanoids (i.e., *Pseudocalanus minutus*), which characterize the plankton community in the region's surface waters.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
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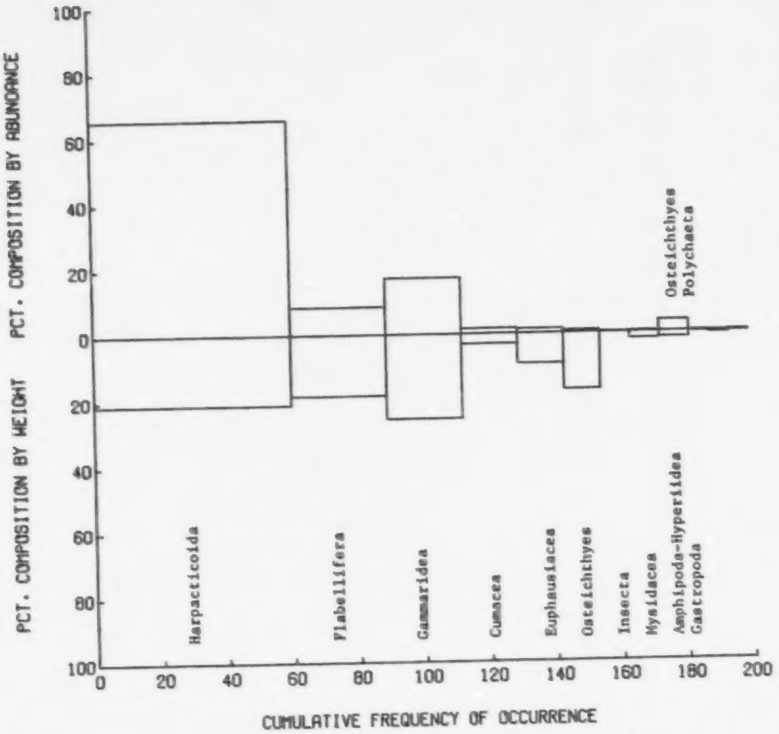

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
HARPACTICOIDA	60.00	65.53	21.10	5197.8	56.40
FLABELLIFERA	29.00	6.48	18.39	779.2	8.50
GAMMARIDEA	23.00	17.14	25.59	982.8	10.70
CUMACEA	17.00	1.55	3.06	78.4	.90
EUPHAUSIACEA	14.00	1.25	9.12	145.2	1.60
OSTEICHTHYES	11.00	.64	17.18	196.0	2.10
INSECTA	9.00	.11	.05	1.4	.00
MYSIDACEA	9.00	.23	1.99	20.0	.20
AMPHIPODA-HYPERIIDEA	9.00	3.33	1.82	46.3	.50
GASTROPODA	6.00	.11	.15	1.6	.00
OSTEICHTHYES	5.00	.08	.61	4.1	.10
POLYCHAETA	6.00	.23	.15	2.3	.00

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.47	.18	.34
SHANNON-WEINER DIVERSITY	1.59	2.63	1.45
EVENNESS INDEX	.44	.73	.46

Fig. B-7. IRI prey spectrum of juvenile chum salmon in shallow sublittoral waters of northern Puget Sound.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD. STATION ALSTA

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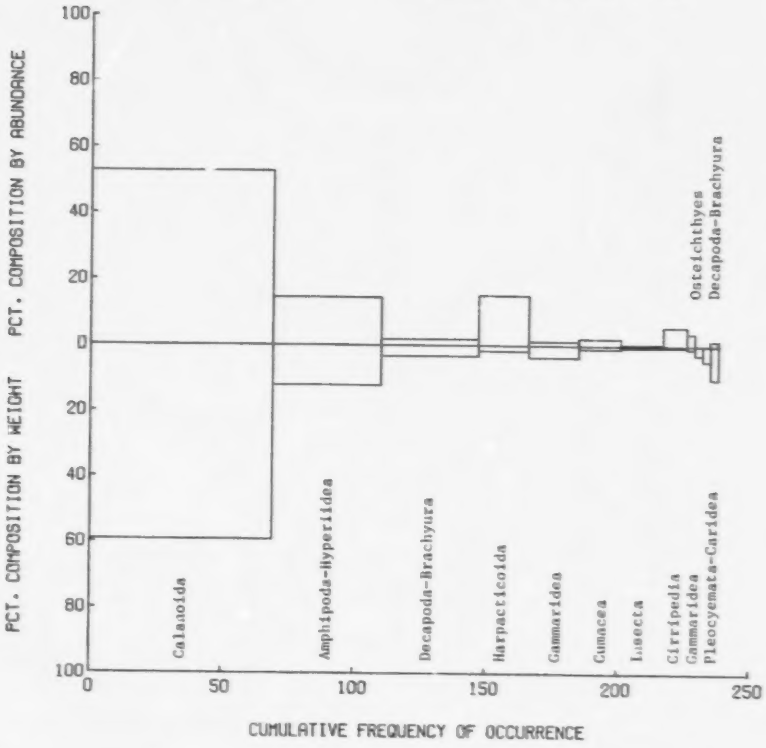
(CHUM SALMON) ADJUSTED SAMPLE SIZE = 32

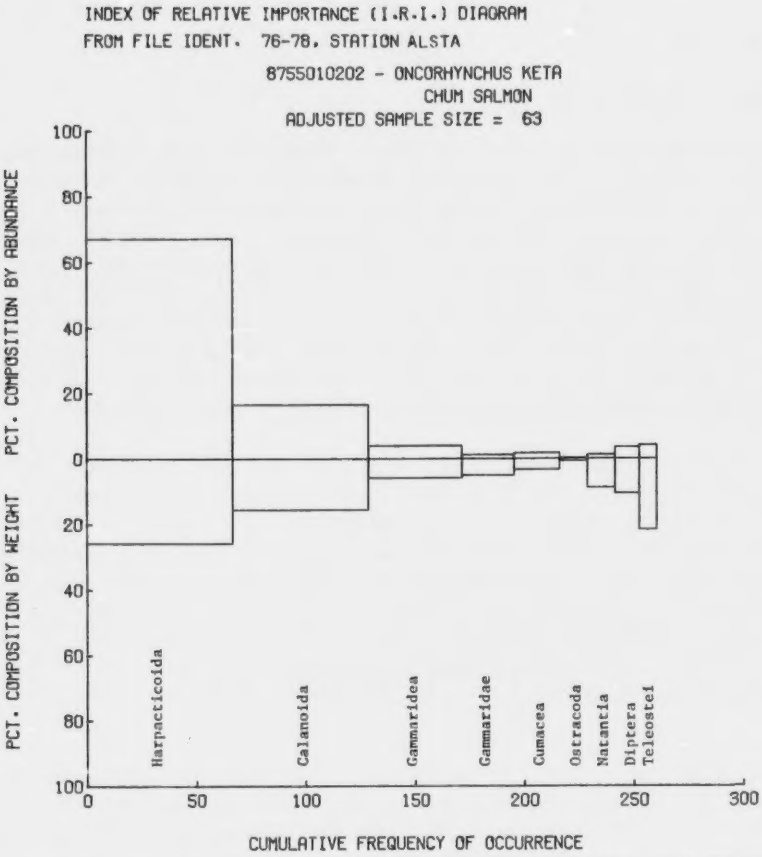


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CALANOIDA	69.00	52.81	59.25	7732.1	80.40
AMPHIPODA-HYPERIIDEA	41.00	14.51	12.14	1092.7	11.40
DECAPODA-BRACHYURA	37.00	1.47	3.27	190.2	2.00
HARPACTICOIDA	19.00	15.15	1.66	319.4	3.30
GAMMARIDEA	19.00	1.29	3.63	93.5	1.00
CUMACEA	16.00	2.16	.92	49.3	.50
INSECTA	16.00	.39	.51	14.2	.20
CIRRIPEDIA	9.00	5.64	.41	54.5	.60
GAMMARIDEA	3.00	3.67	.92	13.8	.10
PLEOCYEMATA-CARIDEA	3.00	.11	2.81	5.8	.10
OSTEICHTHYES	3.00	.04	4.69	14.2	.20
DECAPODA-BRACHYURA	3.00	1.48	10.12	34.8	.40

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.33	.38	.66
SHANNON-WEINER DIVERSITY	2.16	2.13	1.12
EVENNESS INDEX	.60	.59	.31

Fig. B-8. IRI prey spectrum of juvenile chum salmon in neritic waters of northern Puget Sound.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
HARPACTICOIDA	66.67	67.14	25.83	6198.4	66.16
CALANOIDA	61.90	16.50	15.55	1983.8	21.17
GAMMARIDEA	42.86	3.97	5.87	421.6	4.50
GAMMARIDAE	23.81	1.23	5.06	149.6	1.60
CUMACEA	20.63	1.71	3.33	104.0	1.11
OSTRACODA	12.70	.22	.74	12.2	.13
NATANTIA	12.70	1.23	8.91	128.8	1.37
DIPTERA	11.11	3.54	10.68	158.0	1.69
TELEOSTEI	7.94	4.12	21.76	205.4	2.19

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.48	.16	.49
SHANNON-WEINER DIVERSITY	1.67	2.92	1.57
EVENNESS INDEX	.38	.66	.36

Fig. B-9. IRI prey spectrum of juvenile chum salmon from Strait of Juan de Fuca.

Juvenile chum salmon from nearshore habitats of Kodiak Island had fed principally upon harpacticoid copepods although fish larvae, gammarid amphipods, and mysids comprised much of the prey spectrum in terms of biomass (Harris and Hartt 1977).

Coho Salmon (Juveniles)

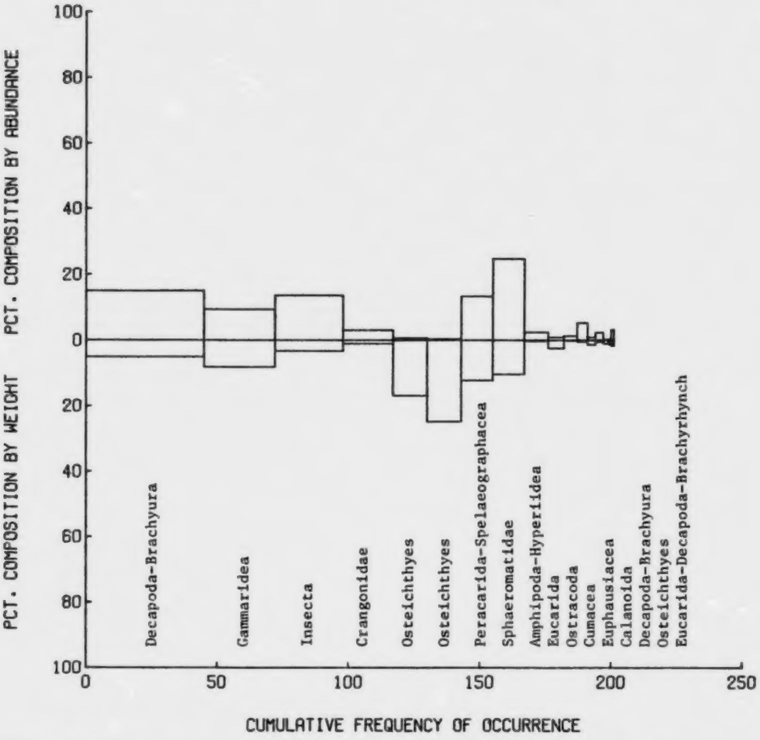
During the DOE Baseline Studies juvenile coho salmon were found throughout the neritic waters of north Puget Sound from April to October. Townet collections at Birch Bay, Eagle Cove, Shannon Point, Cherry Point, and Padilla Bay typically produced the highest catches. The overall prey IRI spectrum (Fig. B-10) showed that juvenile coho in that region fed upon both epibenthic and pelagic organisms, but apparently equally so on those which were available within a certain size range. The pelagic organisms included drift insects (the most commonly taken item), crab zoea and megalops, hyperiid amphipods, and fish. Epibenthic prey included only crustaceans--gammarid amphipods, shrimp (Crangonidae), flabelliferan isopods, and ostracods.

In terms of the total IRI, the highest contributors were fish larvae (23 percent), insects (22 percent) peracaridian crustaceans (15 percent), oniscoidean isopods (14 percent), gammarid amphipods (9 percent), and crab larvae (7 percent). Identifiable amphipods included Eusiroides sp. (the most common), Atylus sp., Allorchestes sp., Eohaustorius sp., Calliopius laeviusculus, Talitroidea sp., Paraphoxus (Trichophoxus) spp., Pontogeneia spp., and unidentified Hyperiidae species. The mysid was Homsiella anomala, the isopods were predominantly Gnorimosphaeroma oregonense, and the calanoid copepod was Epilabidocera amphitrites. The identifiable fish were all larval or juvenile herring.

Although never in high numbers, coho salmon juveniles were frequently encountered in spring and summer beach seine collections at almost all sites along the Strait of Juan de Fuca. Gammarid amphipods (over 90% of the total IRI) and fish larvae (including Pacific herring and Pacific sand lance) were the most important prey; cumaceans, polychaetes, sphaeromatic isopods (Gnorimosphaeroma oregonensis), insects, and mysids were of secondary importance (Fig. B-11). The relative importance of epibenthic crustaceans such as gammarid amphipods, cumaceans, harpacticoid copepods and sphaeromatid isopods, of neritic zooplankton such as crab larvae, hyperiid amphipods and euphausiids, and of fish larvae is sustained in other areas of Puget Sound. Brachyuran crab larvae and euphausiids predominated in the prey spectrum for juvenile coho in Hood Canal (Simenstad & Kinney 1978); those collected over the 1978 outmigration period (late March - mid-June) in Nisqually Reach showed a transition in predominant prey from gammarid amphipods, mysids and harpacticoid copepods early in that period toward euphausiids and crustacean larvae in May and June (Fresh et al. 1979). Although not exceedingly common in the Pacific Biological Station's 1966-68 neritic collections in the Strait of Georgia, juvenile coho preyed exclusively upon large zooplankters (3.5-10 mm), principally the calanoid copepod Calanus plumchrus, the hyperiid amphipod, Parathemisto pacifica, and euphausiids (Euphausia pacific, Thysanoessa raschii and T. spinifera). Fish larvae, including Pacific herring, eulachon (Thaleichthys pacificus), and Pacific sand lance, became prevalent prey after June (Barraclough 1967 a-c; Barraclough & Fulton 1967 and 1968; Robinson et al. 1968 a & b; Barraclough et al. 1968; Robinson 1969).

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD. STATION ALSTA

PREDATOR 8755010203 - ONCORHYNCHUS KISUTCH
(COHO SALMON) ADJUSTED SAMPLE SIZE = 140

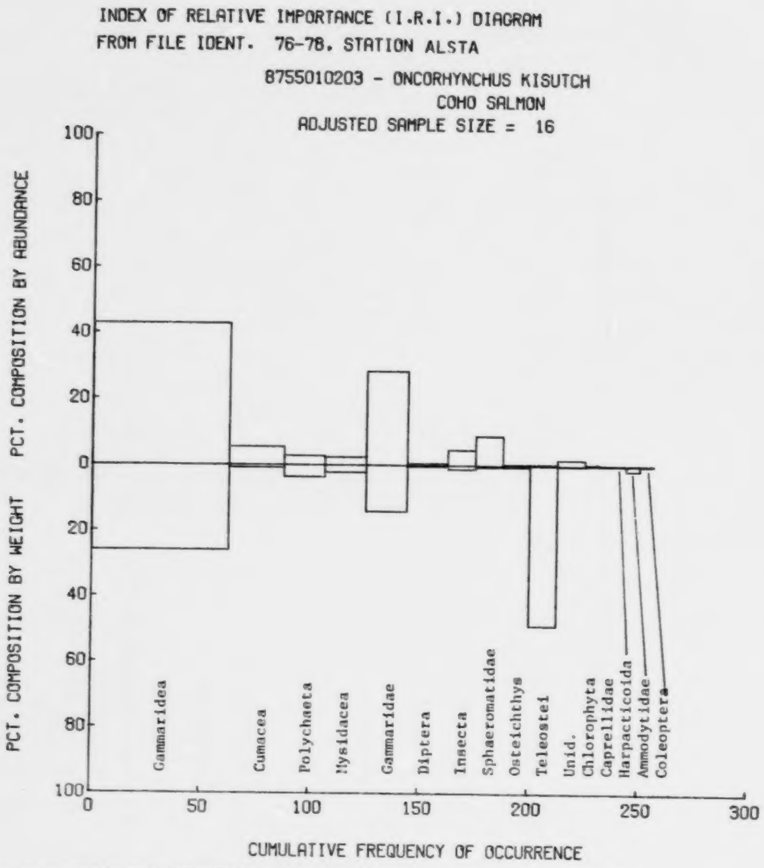


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
DECAPODA-BRACHYURA	45.00	15.03	5.07	904.5	26.30
GAMMARIDEA	27.00	9.35	8.14	472.2	13.70
INSECTA	26.00	13.61	3.25	439.4	12.70
CRANGONIDAE	19.00	3.00	1.05	76.9	2.20
OSTEICHTHYES	13.00	.63	16.84	227.1	6.60
OSTEICHTHYES	13.00	.35	24.78	498.8	14.50
PERACARIDA-SPELAEOGRAPHACEA	12.00	13.36	12.19	306.6	8.90
SPHAEROMATIDAE	12.00	24.73	10.30	420.4	12.20
AMPHIPODA-HYPERIIDEA	9.00	2.39	.34	24.6	.70
EUCARIDA	6.00	.84	2.49	20.0	.60
OSTRACODA	5.00	1.25	.12	6.8	.20
CUMACEA	4.00	5.24	.46	22.8	.70
EUPHAUSIACEA	3.00	.84	1.37	6.6	.20
CALANOIDA	3.00	2.25	.52	8.3	.20
DECAPODA-BRACHYURA	2.00	.29	1.09	2.7	.10
OSTEICHTHYES	1.00	.18	1.17	1.4	.10
EUCARIDA-DECAPODA-BRACHYRHYNCH	1.00	3.15	1.64	4.8	.10

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.13	.13	.15
SHANNON-WEINER DIVERSITY	3.10	2.96	2.97
EVENNESS INDEX	.76	.72	.73

Fig. B-10. IRI prey spectrum of juvenile coho salmon in northern Puget Sound.



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                                  FREQ   NUM.   GRAV.  PREY     PERCENT
        PREY ITEM                 OCCUR  COMP.  COMP.  I.R.I.   TOTAL IRI
 ---------------------------      -----  -----  -----  ------   ---------

GAMMARIDEA                        62.50  42.83  26.02  4303.3    67.80
CUMACEA                           25.00   5.45    .87   158.1     2.49
POLYCHAETA                        18.75   2.83   3.68   122.1     1.92
MYSIDACEA                         18.75   2.42   2.24    87.5     1.38
GAMMARIDAE                        18.75  28.49  14.10   798.5    12.58
DIPTERA                           18.75    .61    .42    19.3      .30
INSECTA                           12.50   4.65   1.23    73.4     1.16
SPHAEROMATIDAE                    12.50   8.89    .45   116.7     1.84
OSTEICHTHYS                       12.50    .40    .44    10.6      .17
TELEOSTEI                         12.50    .40  48.81   615.2     9.69
UNIDENTIFIED                      12.50   1.82    .17    24.8      .39
CHLOROPHYTA                        6.25    .40    .00     2.5      .04
CAPRELLIDAE                        6.25    .20    .02     1.4      .02
HARPACTICOIDA                      6.25    .20    .00     1.3      .02
AMMODYTIDAE                        6.25    .20   1.52    10.8      .17
COLEOPTERA                         6.25    .20    .00     1.3      .02

  PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
  COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
  (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

     PERCENT DOMINANCE INDEX             .28    .33              .49
     SHANNON-WEINER DIVERSITY           2.38   2.06             1.69
     EVENNESS INDEX                      .59    .51              .42
```

Fig. B-11. IRI prey spectrum of juvenile coho salmon in the Strait of Juan de Fuca.

Sockeye Salmon (Juveniles)

Except for a sizable catch at Birch Bay in May 1976, juvenile sockeye were infrequently encountered during the DOE Baseline Studies in the neritic waters of north Puget Sound, usually only in the northeastern study sites during May through September.

Juvenile sockeye salmon were dependent upon euphausiids, shrimp and fish larvae, and general (unidentifiable) eucaridan crustaceans (typically epibenthic organisms), and to a lesser degree upon pelagic and surface prey items such as calanoid copepods, barnacle nauplii, and hyperiid amphipods (Fig. B-12).

No juvenile sockeye were collected during the MESA collections in the Strait of Juan de Fuca (Cross et al. 1978).

Juvenile sockeye salmon captured in the neritic waters of the Strait of Georgia (Barraclough 1967 a-c; Barraclough & Fulton 1967 and 1968; Robinson et al. 1967 a & b; Barraclough & Fulton 1967 and 1968; Robinson et al. 1967 a & b,; Barraclough et al. 1968; Robinson 1969) had characteristically consumed either drift insects (especially after June), including many dipterans and hymenopterans, or pelagic zooplankters, including calanoid copepods (Calanus plumchrus, Paracalanus parvus, Pseudocalanus minutus, Eucalanus bungi bungi), euphausiids (Thysanoessa raschii), hyperiid amphipds (Parathemisto pacifica), chaetognaths (Sagitta elegans) and larvaens.

Chinook Salmon (Juveniles)

Juvenile chinook salmon were ranked among the 10 most common neritic fishes in north Puget Sound and were the most common juvenile salmonid in the region's neritic waters (Fresh 1979). All the stomach samples originated from the eastern study sites from May through September with the largest samples from Padilla Bay, Birch Bay, and Burrows Island in July and August.

The generalized prey spectrum from the DOE collections indicated both epibenthic and pelagic feeding beahvior with an emphasis on the latter (Fig. B-13). Overall, the most important prey taxa were crab megalops, insects, juvenile and larval fish (Pacific herring surf smelt, Hypomesus pretiosus) and gammarid amphipods.

Juvenile chinook salmon were caught in beach seine collections in southern North Sound (Guemes Island sites, Padilla and Fidalgo bays) during July and August. Their diet was almost entirely taken up by crab larvae (megalops) which constituted 89 percent of the total IRI for that species. Insects, gammarid amphipods, and polychaetes formed the majority of the remaining incidental prey organisms.

In the Strait of Juan de Fuca collections chinook salmon juveniles and a few maturing residents were common to both beach seine and townet collections from May and August, especially at Morse Creek and Beckett Point. Dipteran insects, shrimp larvae, and gammarid amphipods predominated in the

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INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
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        (SOCKEYE SALMON       )   ADJUSTED SAMPLE SIZE =  39
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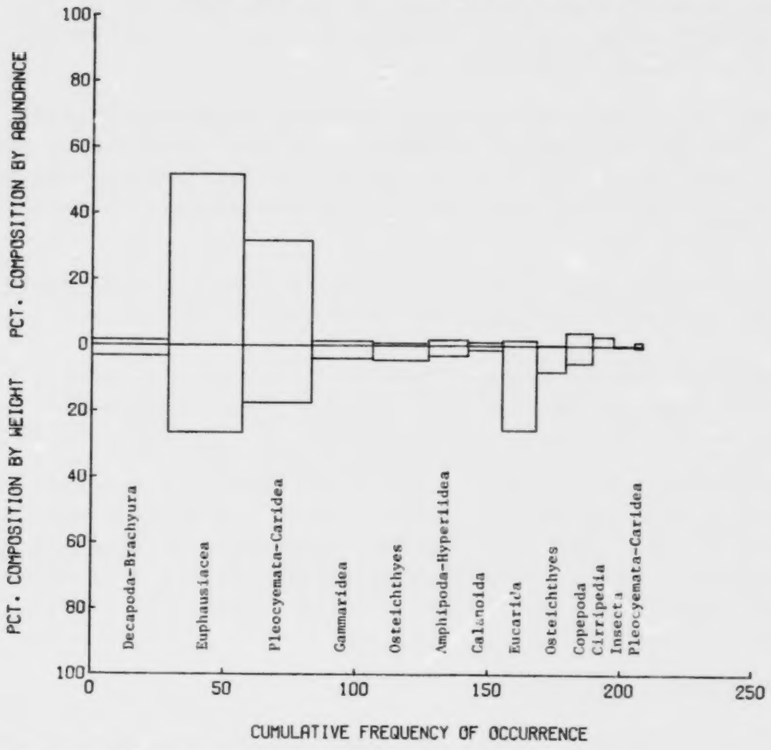

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                                     FREQ   NUM.   GRAV.  PREY     PERCENT
           PREY ITEM                 OCCUR  COMP.  COMP.  I.R.I.   TOTAL IRI
    ----------------------------     -----  -----  -----  ------   ---------

    DECAPODA-BRACHYURA               29.00   1.59   3.21   139.2     3.10
    EUPHAUSIACEA                     28.00  51.71  26.46  2188.8    48.60
    PLEOCYEMATA-CARIDEA              26.00  31.75  17.37  1277.1    28.40
    GAMMARIDEA                       23.00   1.31   3.91   120.1     2.70
    OSTEICHTHYES                     21.00    .75   4.40   108.2     2.40
    AMPHIPODA-HYPERIIDEA             15.00   1.73   3.08    72.2     1.60
    CALANOIDA                        13.00    .98   1.32    29.9      .70
    EUCARIDA                         13.00   1.60  25.63   354.0     7.90
    OSTEICHTHYES                     11.00    .16   7.89    88.6     2.00
    COPEPODA                         10.00   3.96   5.29    92.5     2.10
    CIRRIPEDIA                        8.00   2.77    .08    22.8      .50
    INSECTA                           8.00    .16    .15     2.5      .10
    PLEOCYEMATA-CARIDEA               3.00   1.14    .57     5.1      .10

      PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
      COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
      (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

        PERCENT DOMINANCE INDEX              .37    .18                .33
        SHANNON-WEINER DIVERSITY            1.94   2.81               2.17
        EVENNESS INDEX                       .52    .76                .59
```

Fig. B-12. IRI prey spectrum of juvenile sockeye salmon in the neritic waters of northern Puget Sound.

Reproduced from best available copy.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
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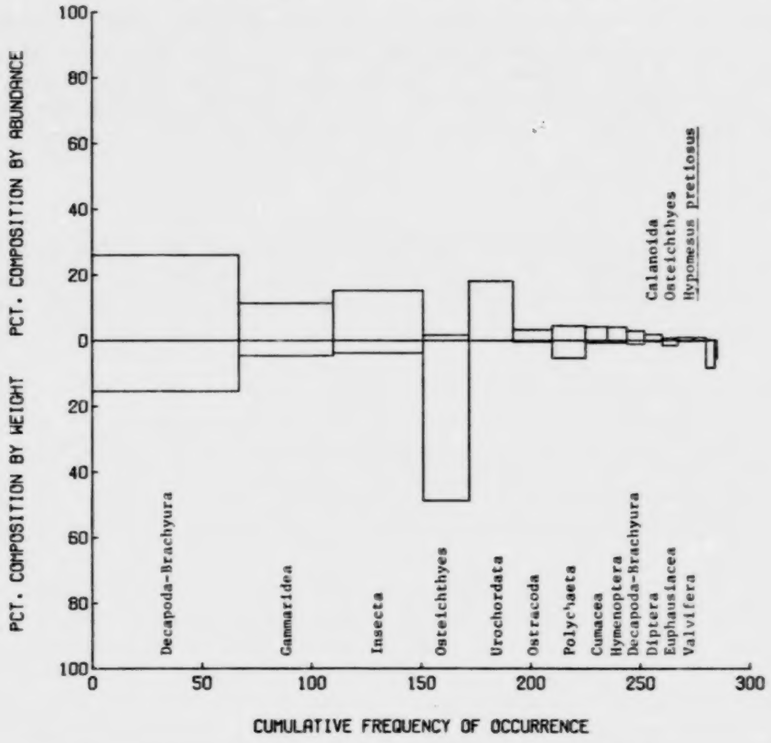
PREDATOR 8755010206 - ONCORHYNCHUS TSHAWYTSCHA
(CHINOOK SALMON) ADJUSTED SAMPLE SIZE = 131



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
DECAPODA-BRACHYURA	67.00	26.09	15.43	2781.4	45.70
GAMMARIDEA	43.00	11.36	4.57	685.0	11.30
INSECTA	41.00	15.21	3.81	779.8	12.80
OSTEICHTHYES	21.00	1.65	48.77	1058.8	17.40
UROCHORDATA	20.00	18.06	.09	363.0	6.00
OSTRACODA	18.00	3.22	.39	65.0	1.10
POLYCHAETA	15.00	4.49	5.35	146.6	2.40
CUMACEA	10.00	4.14	.67	48.1	.80
HYMENOPTERA	9.00	3.97	.64	41.5	.70
DECAPODA-BRACHYURA	8.00	2.88	1.15	32.2	.50
DIPTERA	8.00	1.80	.27	16.6	.30
EUPHAUSIACEA	7.00	.66	1.54	15.4	.30
VALVIFERA	7.00	.90	.27	8.2	.10
CALANOIDA	6.00	.78	.22	6.0	.10
OSTEICHTHYES	4.00	.12	8.30	33.7	.60
HYPOMESUS PRETIOSUS	1.00	.02	5.63	5.7	.10

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

		NUM. COMP.	GRAV. COMP.		PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX		.14	.28		.27
SHANNON-WEINER DIVERSITY		2.98	2.43		2.40
EVENNESS INDEX		.75	.61		.60

Fig. B-13. IRI prey spectrum of juvenile chinook salmon in northern Puget Sound.

most diverse prey spectrum of all the juvenile salmonids (Fig. B-14). Osstracods, post-larval fishes (including Pacific sand lance and rockfish, Scorpaenidae), polychaetes (including Syllidae), mysids, and calanoid copepods were of secondary importance.

Juvenile chinook from Hood Canal and southern Puget Sound had remarkably similar prey spectra (Simenstad and Kinney 1978; Fresh et al. 1979) to those from northern Puget Sound and the Strait of Juan de Fuca; insects (principally dipterans), crab and shrimp larvae, shrimp (principally crangonids), and fish larvae also formed the most prevalent prey organisms in these regions.

Surf Smelt

Surf smelt were similar to Pacific herring in their distribution through northern Puget Sound. Eastern townet sites, especially Birch Bay and Padilla Bay, sampled during the DOE studies produced large samples. The total sample was approximately two-thirds juveniles and one-third adults.

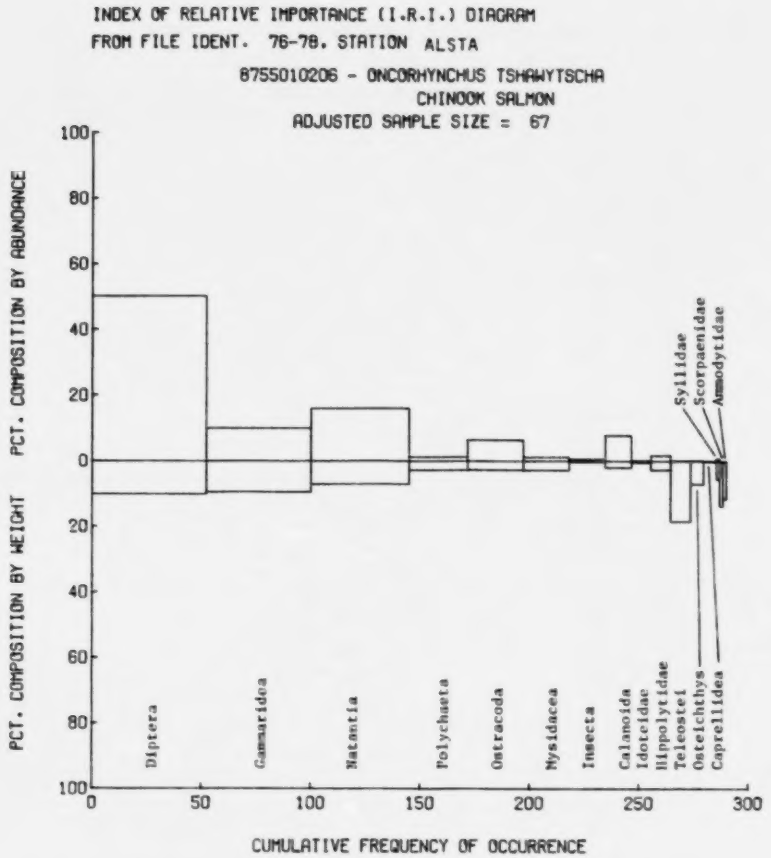
The prey spectrum from this region (Fig. B-15) include both pelagic and epibenthic organisms as important prey. According to the total IRI, epibenthic flabelliferan isopods were the most important prey organisms followed by cumaceans, larvaceans, and calanoid copepods. One specimen of *Lophopanopeus bellus* was also found in a stomach but was not included in the IRI graph because it did not represent a significant portion of the stomach contents.

Surf smelt were also caught in the shallow sublittoral zone all along the eastern shoreline of northern Puget Sound during beach seine collections; the highest catches obtained for stomach samples were from Cherry Point in December. Of the diverse prey organisms consumed, 26.7 percent of the total IRI were larvaceans; 27.0 percent, caprellids; 9.9 percent, gammarid amphipods; 11.8 percent, calanoid copepods; 7.7 percent, penaeid shrimp; 5.0 percent, harpacticoid copepods (Fig. B-16). Thus, close to 60 percent of the prey from these collections were epibenthic organisms.

All life history stages of surf smelt were commonly caught throughout the Strait of Juan de Fuca during the MESA studies, but catches were highest at Twin Rivers, Morse Creek, Alexander's Beach, and West Beach.

Although not among the most abundant species caught in the shallow sublittoral zone (approx. 10th one year, not caught the next), surf smelt usually ranked in the top five species sampled in the neritic waters by the townet (Cross et al. 1978).

In accordance with their predominantly neritic distribution, calanoid copepods provided the most trophic input (80.6% of total IRI) to the overall surf smelt prey spectrum (Fig. B-17). Harpacticoid copepods (12.7%) and polychaete annelids (3.8%) were second in importance. Fish, although infrequently consumed, accounted for 27.5% of the total prey biomass.



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                                  FREQ   NUM.   GRAV.   PREY   PERCENT
        PREY ITEM                 OCCUR  COMP.  COMP.   I.R.I. TOTAL IRI
---------------------------       -----  -----  -----  ------  ---------

DIPTERA                           52.24  50.23  10.15  3154.1    52.55
GAMMARIDEA                        47.76  10.03   9.55   935.2    15.58
NATANTIA                          44.78  16.02   7.06  1033.7    17.22
POLYCHAETA                        26.87   1.24   2.78   108.0     1.80
OSTRACODA                         25.37   6.37   2.70   229.9     3.83
MYSIDACEA                         20.90   1.22   2.81    84.3     1.40
INSECTA                           16.42    .57    .29    14.1      .24
CALANOIDA                         11.94   7.83   1.97   117.0     1.95
IDOTEIDAE                          8.96    .22    .37     5.3      .09
HIPPOLYTIDAE                       8.96   1.74   2.74    40.1      .67
TELEOSTEI                          8.96    .13  18.49   166.7     2.78
OSTEICHTHYS                        5.97    .22   7.00    43.1      .72
CAPRELLIDEA                        5.97    .09    .05      .8      .01
SYLLIDAE                           1.49    .83   5.50     9.4      .16
SCORPAENIDAE                       1.49    .02  13.64    20.4      .34
AMMODYTIDAE                        1.49    .02  11.44    17.1      .28

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX              .30    .10                .33
      SHANNON-WEINER DIVERSITY            2.50   3.64               2.21
      EVENNESS INDEX                       .48    .69                .42
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Fig. B-14. IRI prey spectrum of juvenile chinook salmon in the Strait of Juan de Fuca.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD. STATION ALSTA

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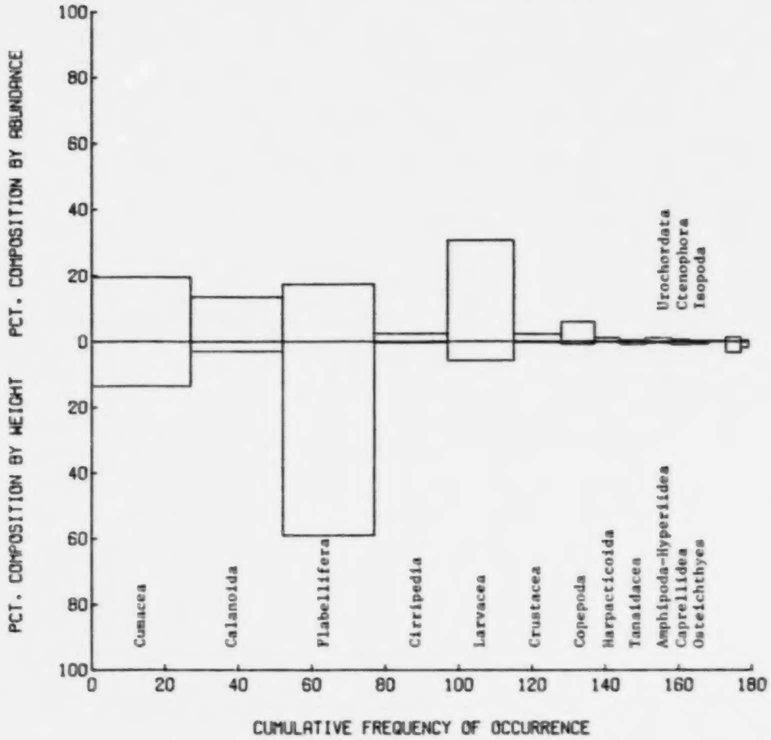

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CUMACEA	27.00	19.62	13.55	895.6	21.80
CALANOIDA	25.00	13.60	3.01	415.2	10.10
FLABELLIFERA	25.00	17.50	59.02	1913.0	46.60
CIRRIPEDIA	20.00	2.42	.27	53.8	1.30
LARVACEA	18.00	30.65	5.82	656.5	16.00
CRUSTACEA	13.00	2.21	.27	32.2	.80
COPEPODA	9.00	5.95	.78	60.6	1.50
HARPACTICOIDA	7.00	1.07	.10	8.2	.20
TANAIDACEA	7.00	.36	.78	8.0	.20
AMPHIPODA-HYPERIIDEA	7.00	1.09	.41	10.5	.30
CAPRELLIDEA	5.00	.54	.85	6.9	.20
OSTEICHTHYES	5.00	.19	.64	4.2	.10
UROCHORDATA	5.00	.19	.00	.9	.00
CTENOPHORA	4.00	1.26	3.28	18.2	.40
ISOPODA	2.00	.32	1.79	19.0	.50

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.19	.37	.30
SHANNON-WEINER DIVERSITY	2.66	1.80	2.14
EVENNESS INDEX	.68	.47	.56

Fig. B-15. IRI prey spectrum of surf smelt in northern Puget Sound.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
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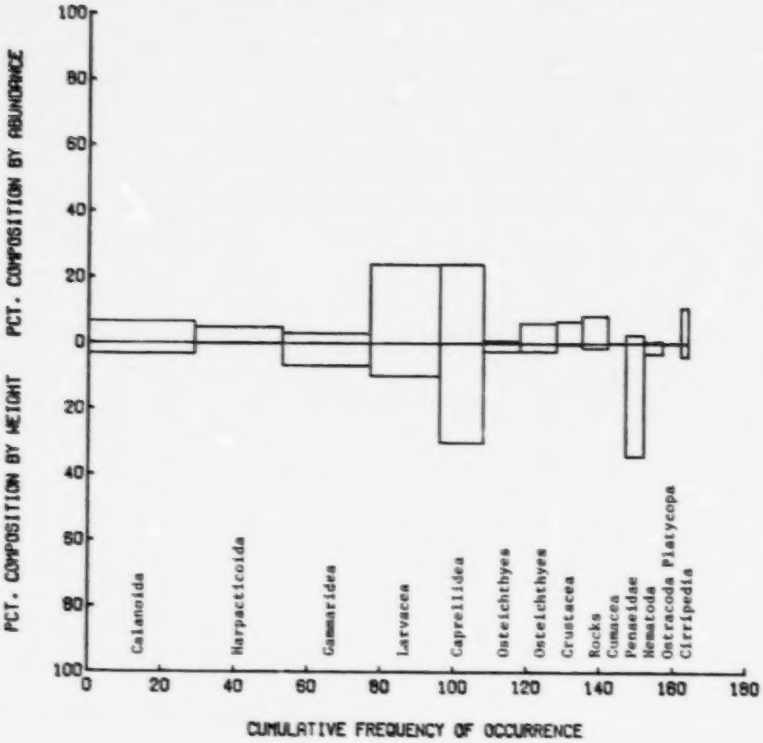
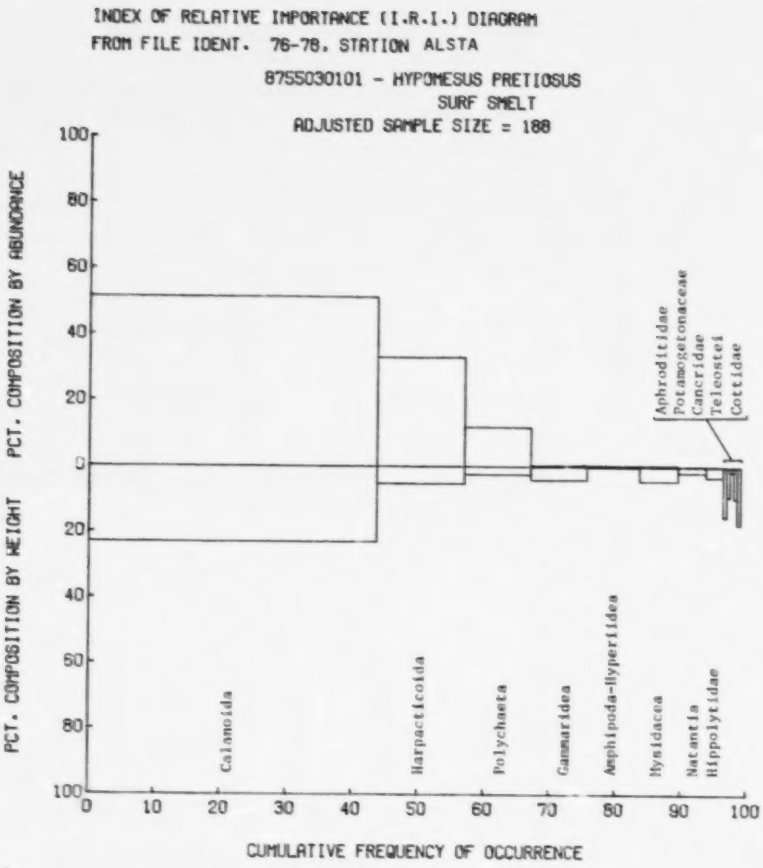


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CALANOIDA	29.00	6.52	3.31	285.1	11.80
HARPACTICOIDA	24.00	4.90	.12	120.5	5.00
GAMMARIDEA	24.00	3.03	6.86	237.4	9.90
LARVACEA	19.00	23.87	9.95	642.6	26.70
CAPRELLIDEA	12.00	23.92	30.25	650.0	27.00
OSTEICHTHYES	10.00	.75	2.56	33.1	1.40
OSTEICHTHYES	10.00	6.06	2.56	86.2	3.60
CRUSTACEA	7.00	6.67	.35	49.1	2.00
ROCK	7.00	8.34	1.45	68.5	2.80
CUMACEA	5.00	.09	.00	.4	.00
PENAEIDAE	5.00	2.56	34.32	184.4	7.70
NEMATODA	5.00	.70	3.20	19.5	1.00
OSTRACODA PLATYCOPA	5.00	.14	.00	.7	.00
CIRRIPEDIA	2.00	10.82	4.07	29.8	1.20

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.15	.23	.18
SHANNON-WEINER DIVERSITY	3.02	2.56	2.87
EVENNESS INDEX	.79	.71	.80

Fig. B-16. IRI prey spectrum of surf smelt along eastern shoreline of northern Puget Sound.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CALANOIDA	43.62	51.34	23.08	3246.1	80.60
HARPACTICOIDA	13.30	33.06	5.24	509.3	12.65
POLYCHAETA	10.11	11.88	2.47	145.1	3.60
GAMMARIDEA	8.51	.40	4.11	38.4	.95
AMPHIPODA-HYPERIIDEA	7.98	.31	.19	4.0	.10
MYSIDACEA	5.95	.42	4.46	28.6	.71
NATANTIA	4.26	.11	1.88	8.5	.21
HIPPOLYTIDAE	2.66	.08	3.23	8.8	.22
APHRODITIDAE	.53	.01	15.30	8.1	.20
POTAMOGETONACEAE	.53	.01	9.12	4.9	.12
CANCRIDAE	.53	.01	1.44	.8	.02
TELEOSTEI	.53	.01	9.72	5.2	.13
COTTIDAE	.53	.01	17.68	9.4	.23

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.39	.13	.67
SHANNON-WEINER DIVERSITY	1.70	3.28	1.06
EVENNESS INDEX	.34	.65	.21

Fig. B-17. IRI prey spectrum of surf smelt in Strait of Juan de Fuca.

Longfin Smelt

Longfin smelt were not a common component of the DOE collections in northern Puget Sound. Three adult longfin smelt caught during a September townet collection at Cherry Point had consumed principally crab larvae, calanoid copepods, and mysids, with supplemental contributions by hyperiid and gammarid amphipods. This prey composition suggested a basically pelagic feeding beahvior.

In the Strait of Juan de Fuca, however, longfin smelt of all life-history stages were caught frequently, and were especially abundant in August and October townet collections at Twin Rivers and Pillar Point and in January beach seine collections at West Beach. Epibenthic crustaceans predominated the overall prey spectrum of longfin smelt (Fig. B-18). Gammarid amphipods accounted for 61.6% of the total IRI; mysids (*Archaeomysis grebnitzki* and *Neomysis* sp.), 24.4%; and cumaceans, 5.1%. Pelagic prey organisms were not important.

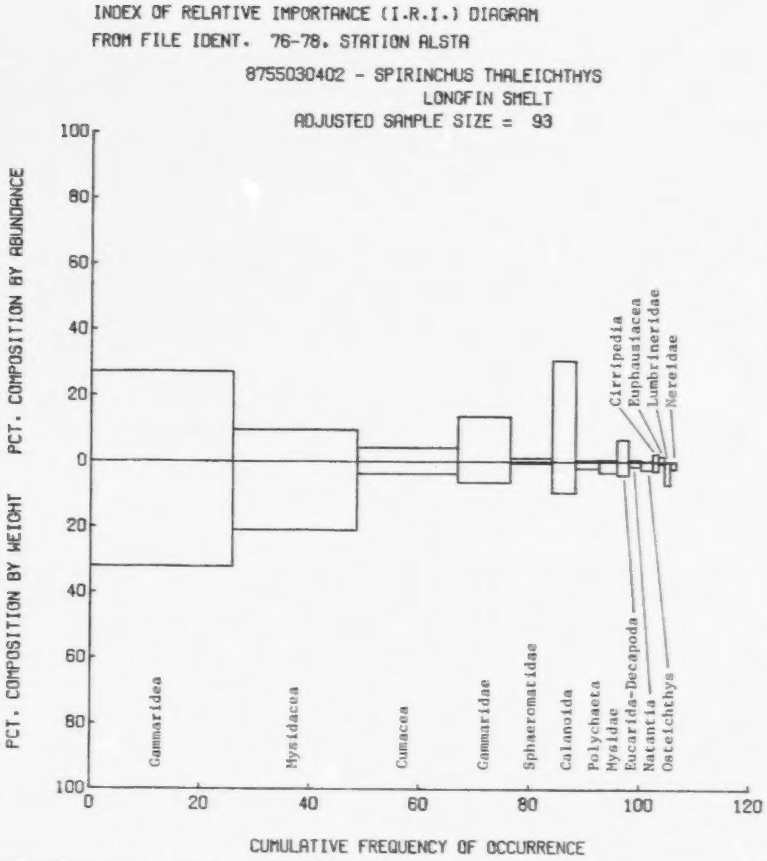
Northern Clingfish

Northern clingfish were common members of the intertidal fish assemblages documented during the MESA studies in the Strait of Juan de Fuca; they were found to be especially abundant at North Beach, Morse Creek, Observatory Point, Twin Rivers, and Slip Point. Epibenthic and benthic crustaceans and benthic molluscs were the most important prey organisms (Fig. B-19). Gammarid amphipods and isopods (*Gnorimosphaeroma oregonensis*, *Exosphaeroma amplicauda*, *Dynamenella sheareri*, *Idotea urotoma*, and *Pentitotea montereyensis*) made up 68.1% of the total IRI, and limpets (*Collisella pelata*, *C. digitalis*, *C. strigatella*, *Notoacmea scutum*, *N. persona*, and *N. fenestrata*), 24%.

The prey spectrum of northern clingfish in the littoral environs of northern California (Johnson 1970)was very similar to that of the Strait of Juan de Fuca; gammarid amphipods (specifically *Amphithoe* sp.). flabelliferan isopods, and benthic gastropods (*Acumaea* sp., *Nassarius* sp.) were the principal prey organisms in the spectrum (Fig. B-20). Northern clingfish collected in the rocky/kelp bed habitat on theouter coast of Vancouver Island appeared to have a relatively similar prey spectrum including isopods (26.7% by weight), unidentified crustaceans (26.7%) and chitons (20.0%) (Leaman 1976).

Pacific Tomcod (juvenile)

During the DOE Baseline Studies in northern Puget Sound, juvenile Pacific tomcod were often caught in large numbers during the beach seine collections along the eastern shoreline, especially at Shannon Point in July and Birch Bay in December. Penaeid shrimp (28.9) percent of total IRI), gammarid amphipods (38.0) percent of total IRI) and calanoid copepods (19.6 percent of total IRI) composed the majority of the prey organisms from these samples (Fig. B-21). This composition suggests a predominantly epibenthic planktivores feeding beahvior but with some neritic feeding, also, perhaps at night.

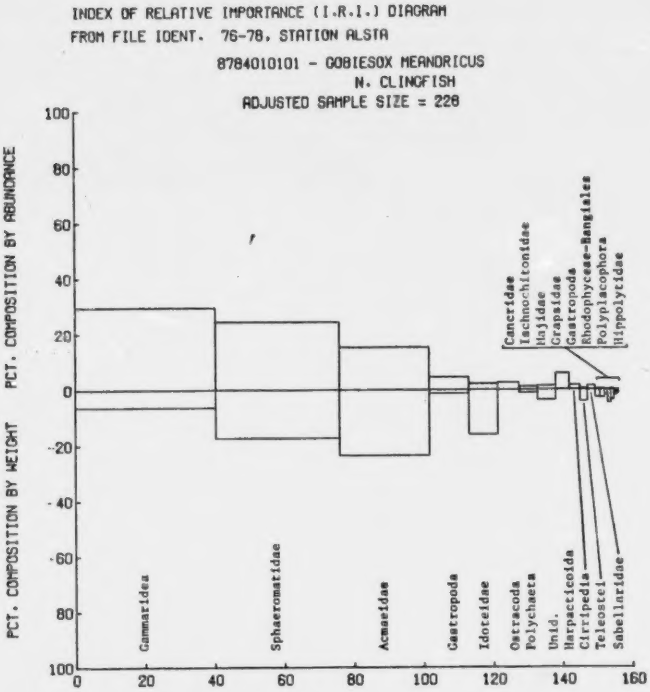


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	25.81	27.17	32.21	1532.3	54.31
MYSIDACEA	22.58	9.58	20.96	689.6	24.44
CUMACEA	18.28	4.20	3.70	144.4	5.12
GAMMARIDAE	9.68	13.65	6.41	194.1	6.88
SPHAEROMATIDAE	7.53	.98	.56	11.6	.41
CALANOIDA	4.30	30.64	9.40	172.2	6.10
POLYCHAETA	4.30	.46	1.97	10.5	.37
MYSIDAE	3.23	.52	3.34	12.5	.44
EUCARIDA-DECAPODA	2.15	6.76	4.14	23.4	.83
NATANTIA	2.15	.59	1.48	4.5	.16
OSTEICHTHYS	2.15	.26	2.47	5.9	.21
CIRRIPEDIA	1.08	2.43	2.82	5.6	.20
EUPHAUSIACEA	1.08	1.64	.52	2.3	.08
LUMBRINERIDAE	1.08	.07	6.90	7.5	.27
NEREIDAE	1.08	.07	2.16	2.4	.08

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.20	.17		.37
SHANNON-WEINER DIVERSITY		2.74	3.13		1.96
EVENNESS INDEX		.63	.72		.45

Fig. B-18. IRI prey spectrum of longfin smelt in the Strait of Juan de Fuca.



INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA
8784010101 - GOBIESOX MEANDRICUS
N. CLINGFISH
ADJUSTED SAMPLE SIZE = 228

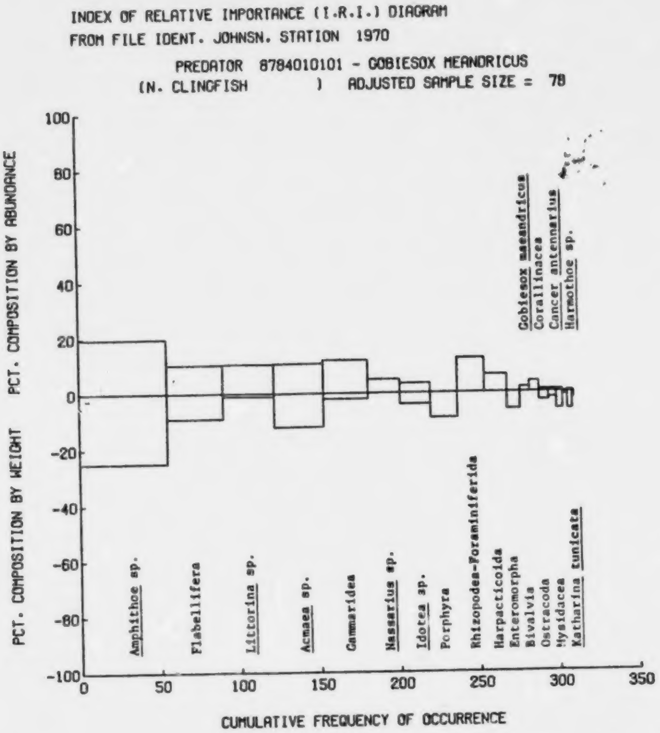
PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	40.35	29.51	6.36	1447.4	33.77
SPHAEROMATIDAE	35.53	24.40	17.32	1482.3	34.59
ACMAEIDAE	25.88	15.25	23.63	1006.2	23.48
GASTROPODA	11.40	4.53	1.31	66.6	1.55
IDOTEIDAE	8.33	2.06	16.14	151.6	3.54
OSTRACODA	6.14	2.56	.02	15.8	.37
POLYCHAETA	5.26	1.07	1.08	11.3	.26
UNIDENTIFIED	5.26	1.32	3.73	26.6	.62
HARPACTICOIDA	3.95	5.77	.02	22.9	.53
CIRRIPEDIA	3.07	1.57	.02	4.9	.11
TELEOSTEI	2.19	.41	4.20	10.1	.24
SABELLARIDAE	2.19	1.40	.08	3.2	.08
CANCRIDAE	1.32	.25	2.82	4.0	.09
ISCHNOCHITONIDAE	1.32	.25	2.93	4.2	.10
MAJIDAE	.88	.16	1.81	1.7	.04
GRAPSIDAE	.88	.16	4.75	4.3	.10
GASTROPODA	.88	.49	3.67	3.7	.09
RHODOPHYCEAE-BANGIALES	.44	.08	1.25	.6	.01
POLYPLACOPHORA	.44	.08	1.96	.9	.02
HIPPOLYTIDAE	.44	.08	1.38	.6	.01

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.18	.13	.29
SHANNON-WEINER DIVERSITY	3.32	3.66	2.09
EVENNESS INDEX	.57	.63	.36

Fig. B-19. IRI prey spectrum of northern clingfish in littoral habitats along the Strait of Juan de Fuca.

Reproduced from best available copy.



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                                  FREQ   NUM.   GRAV.  PREY    PERCENT
          PREY ITEM               OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   ---------------------------    -----  -----  -----  ------  ---------

 AMPHITHOE SP.                    55.00  19.60  25.00  2453.0    45.00
 FLABELLIFERA                     35.00  10.30   9.00   675.5    12.40
 LITTORINA SP.                    32.00  10.50   1.00   368.0     6.80
 ACMAEA SP.                       31.00  10.60  12.00   700.4    12.90
 GAMMARIDEA                       28.00  11.80   2.00   386.4     7.10
 NASSARIUS SP.                    20.00   4.90    .00    98.0     1.80
 IDOTEA SP.                       19.00   3.40   4.00   140.6     2.60
 PORPHYRA                         17.00    .00   9.00   153.0     2.80
 RHIZOPODEA-FORAMINIFERIDA        17.00  12.20    .00   207.4     3.80
 HARPACTICOIDA                    14.00   6.30    .00    88.2     1.60
 ENTEROMORPHA                      8.00    .00   6.00    48.0      .90
 BIVALVIA                          6.00   1.70    .00    10.2      .20
 OSTRACODA                         6.00   3.80    .00    22.8      .40
 MYSIDACEA                         6.00    .80   3.00    22.8      .40
 KATHARINA TUNICATA                5.00    .80   2.00    14.0      .30
 GOBIESOX MAEANDRICUS              4.00    .80   6.00    27.2      .50
 CORALLINACEA                      3.00    .00   1.00     3.0      .00
 CANCER ANTENNARIUS                3.00    .40   6.00    19.2      .40
 HARMOTHOE SP.                     1.00    .20   2.00     2.2      .00

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

       PERCENT DOMINANCE INDEX             .11    .11                .25
       SHANNON-WEINER DIVERSITY           3.34   3.03               2.71
       EVENNESS INDEX                      .84    .80                .66
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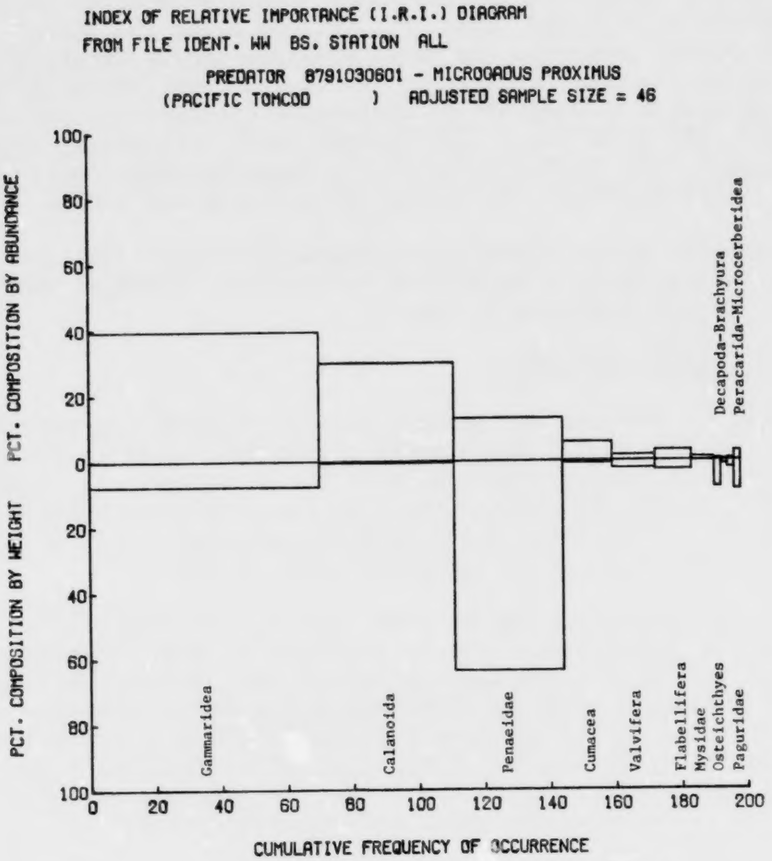
Fig. B-20. IRI prey spectrum of northern clingfish documented for northern California littoral habitats by Johnson (1970).



INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. WW BS. STATION ALL
PREDATOR 8791030601 - MICROGADUS PROXIMUS
(PACIFIC TOMCOD) ADJUSTED SAMPLE SIZE = 46

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                                   FREQ   NUM.   GRAV.  PREY    PERCENT
         PREY ITEM                 OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  ----------------------------     -----  -----  -----  ------  ---------

 GAMMARIDEA                        70.00  39.43   7.67  3297.0    44.70
 CALANOIDA                         41.00  29.81    .52  1243.5    16.90
 PENAEIDAE                         33.00  12.94  63.74  2530.4    34.50
 CUMACEA                           15.00   5.63    .72    95.2     1.30
 VALVIFERA                         13.00   1.64   2.32    51.5      .70
 FLABELLIFERA                      11.00   3.05   2.89    65.3      .90
 MYSIDAE                            7.00    .94    .22     8.1      .00
 OSTEICHTHYES                       2.00    .47   8.12    17.2      .20
 PAGURIDAE                          2.00    .23   1.11     2.7      .00
 DECAPODA-BRACHYURA                 2.00    .47   2.31     5.6      .00
 PERACARIDA-MICROCERBERIDEA         2.00   2.82   8.89    23.4      .30

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX               .27    .43              .35
      SHANNON-WEINER DIVERSITY             2.22   1.88             1.72
      EVENNESS INDEX                        .64    .54              .57
```

Fig. B-21. IRI prey spectrum of juvenile Pacific tomcod from shallow sublittoral habitats along the eastern shoreline of northern Puget Sound.

Pacific tomcod, mainly juveniles (65%), were often caught in abundance in both beach seine and townet collections along the Strait of Juan de Fuca. Beckett Point, Jamestown and Point Williams, Morse Creek, and West Beach contributed the most specimens. The overall prey spectrum (Fig. B-22) is composed almost exclusively of epibenthic crustaceans, including gammarid amphipods (84.3% of total IRI), mysids (4.0% , including Archaeomysis grebnitzki), hippolytid shrimp (3.5%, including Heptacarpus brevirostris), harpacticoid copepods, cumaceans, and unidentified shrimp.

Juvenile tomcod collected in Nisqually Reach (Fresh et al. 1979) had fed predominantly upon epibenthic crustaceans, gammarid amphipods and hippolytid and crangonid shrimp.

Walleye Pollock (juvenile)

Most of the juvenile walleye pollock collected in northern Puget Sound originated from winter beach seine collections at Birch Bay and Cherry Point. Epibenthic or benthic organisms were the principal prey organisms; gammarid amphipods constituted 69.6 percent of the total IRI, valviferan isopods contributed 7.8 percent, while hyperiid amphipods, shrimp, and calanoid copepods made up lower contributions (Fig. B-23).

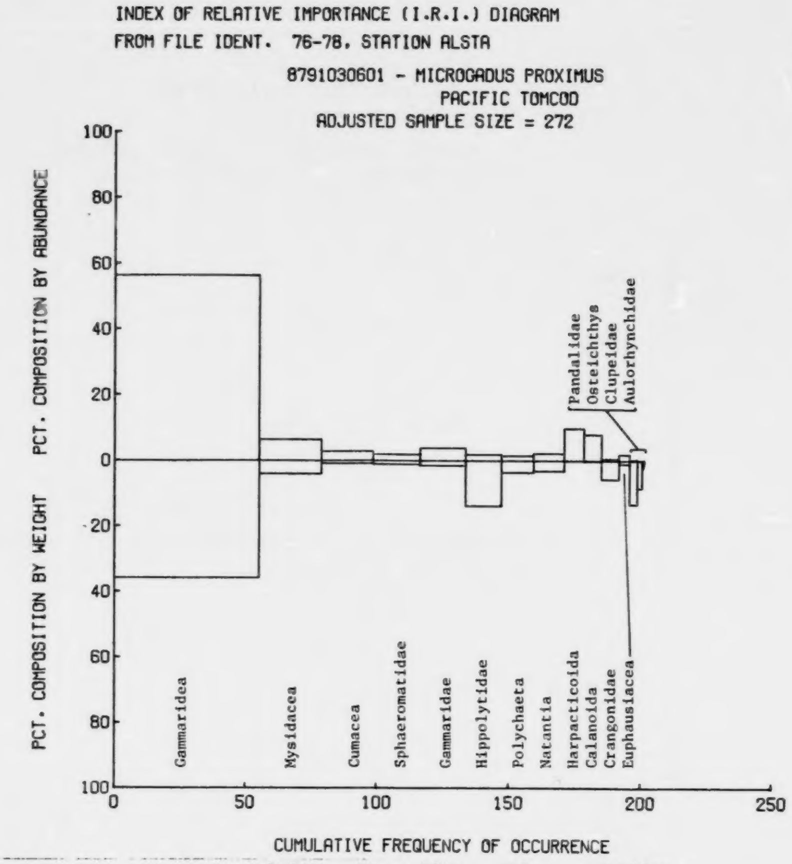
In the Strait of Juan de Fuca, juvenile walleye pollock occurred mainly in fall and winter beach seine collections at Beckett Point and Dungeness Spit and in townet collections at Jamestown and Point Williams. Calanoid copepods, because of their numerical predominance, constituted the most important item in the IRI prey spectrum (67.1% of the total IRI) (Fig. B-24). Gammarid amphipods (15.8%), hippolytid shrimp (including Heptacarpus brevirostris, 8.8%), mysids (including Archaeomysis grebnitzki, 3.1%), and cumaceans (1.1%) were the other prey of significance.

Post-larval pollock collected in late spring in the neritic waters of the Strait of Georgia (Barraclough 1967a-c); Barraclough and Fulton 1967, 1968; Robinson et al. 1967 a, b: Barraclough et al. 1968; Robinson 1969) indicated that calanoid copepods and crustacean larvae were the prevalent organisms consumed by the pelagic juveniles.

Threespine Stickleback

Threespine sticklebacks were the second most frequently encountered neritic species in northern Puget Sound. The more important prey organisms were both epibenthic--harpacticoid copepods (67.0% of the total IRI) and polychaetes (3.7%)--and pelagic--calanoid (14.2%) and euphausiids (13.3%) (Fig. B-25).

Threespine stickleback collected by beach seine in the southern North Sound sites at Guemes Island and Padilla Bay had also consumed epibenthic crustaceans; 76.4 percent of the total IRI was gammarid amphipods, 14.8 percent harpacticioid copepods, 4.6 percent crab larvae and 1.3 percent cumaceans (Fig. B-26).



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	55.15	56.40	35.79	5083.9	82.84
MYSIDACEA	23.53	6.41	4.09	246.9	4.02
CUMACEA	19.85	2.78	.84	71.9	1.17
SPHAEROMATIDAE	17.65	1.88	1.16	53.6	.87
GAMMARIDAE	17.28	3.85	1.55	93.3	1.52
HIPPOLYTIDAE	13.60	1.86	13.86	213.8	3.48
POLYCHAETA	12.13	1.44	3.62	61.4	1.00
NATANTIA	11.76	2.17	3.14	62.4	1.02
HARPACTICOIDA	7.35	9.78	.09	72.6	1.18
CALANOIDA	6.62	7.95	.20	54.0	.88
CRANGONIDAE	6.62	.55	5.65	41.1	.67
EUPHAUSIACEA	4.04	1.84	1.01	11.5	.19
PANDALIDAE	2.94	.24	13.32	39.9	.65
OSTEICHTHYS	1.84	.06	8.34	15.5	.25
CLUPEIDAE	.37	.01	2.19	.8	.01
AULORHYNCHIDAE	.37	.01	1.21	.4	.01

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
(BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.34	.18		.69
SHANNON-WEINER DIVERSITY		2.50	3.20		1.24
EVENNESS INDEX		.47	.60		.23

Fig. B-22. IRI prey spectrum of juvenile Pacific tomcod in the Strait of Juan de Fuca.

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INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. WW  BS, STATION  ALL
            PREDATOR  8791030701 - THERAGRA CHALCOGRAMMA
        (WALLEYE POLLOCK      )   ADJUSTED SAMPLE SIZE = 20
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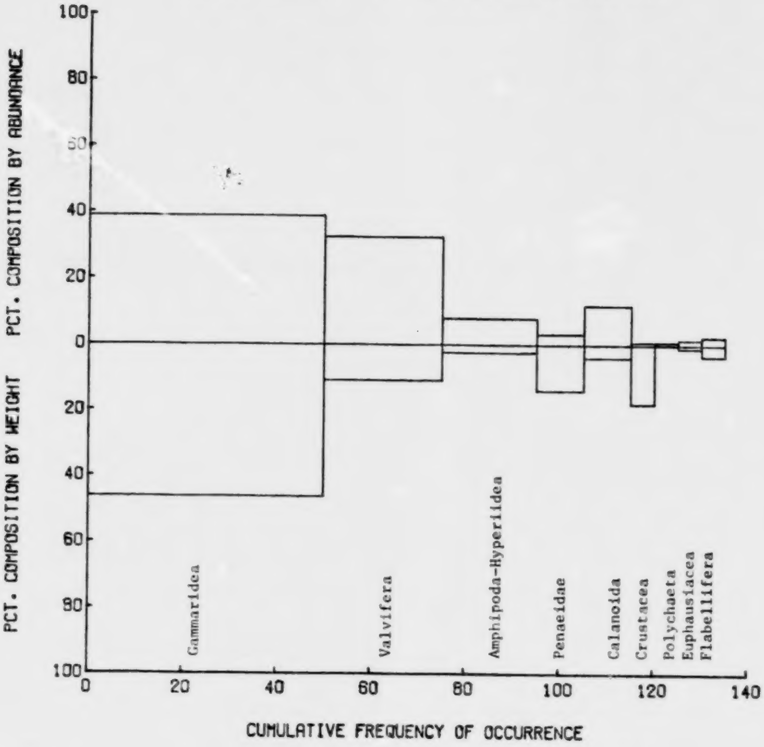

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                              FREQ   NUM.   GRAV.  PREY    PERCENT
       PREY ITEM              OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
----------------------------  -----  -----  -----  ------  ---------

GAMMARIDEA                    50.00  38.89  46.27  4258.0    69.90
VALVIFERA                     25.00  32.44  10.95  1084.7    17.80
AMPHIPODA-HYPERIIDEA          20.00   7.94   2.49   208.6     3.40
PENAEIDAE                     10.00   3.18  13.93   171.1     2.80
CALANOIDA                     10.00  11.90   3.98   158.8     2.60
CRUSTACEA                      5.00    .79  17.91    93.5     1.50
POLYCHAETA                     5.00    .79    .00     4.0      .00
EUPHAUSIACEA                   5.00   1.59   1.00    12.9      .20
FLABELLIFERA                   5.00   2.38   3.48    98.9     1.60

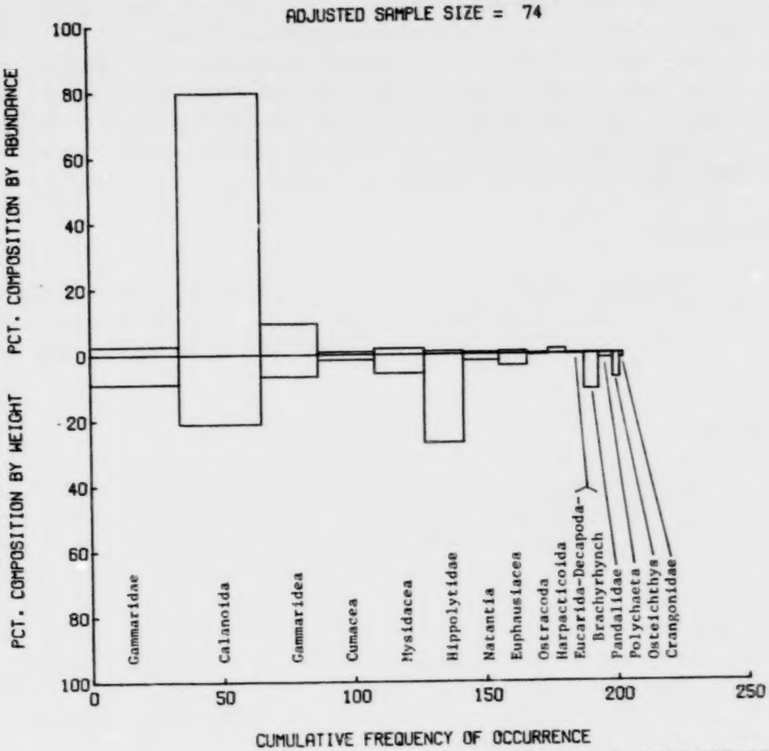
  PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
  COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
  (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

    PERCENT DOMINANCE INDEX             .28    .28               .52
    SHANNON-WEINER DIVERSITY           2.20   2.26              1.46
    EVENNESS INDEX                      .70    .75               .49
```

Fig. B-23. IRI prey spectrum of juvenile walleye pollock in shallow sublittoral habitats along the eastern shore of northern Puget Sound.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA

8791030701 - THERAGRA CHALCOGRAMMA
WALLEYE POLLOCK
ADJUSTED SAMPLE SIZE = 74



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDAE	33.78	2.58	8.92	388.6	8.32
CALANOIDA	31.08	79.71	21.07	3132.3	67.06
GAMMARIDEA	21.62	9.52	6.61	348.9	7.47
CUMACEA	21.62	.82	1.57	51.6	1.10
MYSIDACEA	18.92	1.82	5.75	143.2	3.07
HIPPOLYTIDAE	14.86	.90	26.84	412.3	8.83
NATANTIA	13.51	.49	1.90	32.3	.69
EUPHAUSIACEA	10.81	.77	3.48	45.9	.98
OSTRACODA	8.11	.20	.26	3.7	.08
HARPACTICOIDA	6.76	1.38	.08	9.9	.21
EUCARIDA-DECAPODA-BRACHYRHYNCH	6.76	.15	.15	2.0	.04
PANDALIDAE	5.41	.20	10.70	58.9	1.26
POLYCHAETA	5.41	.15	1.30	7.9	.17
OSTEICHTHYS	2.70	.05	7.24	19.7	.42
CRANGONIDAE	1.35	.03	1.35	1.9	.04

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.65	.15	.47
SHANNON-WEINER DIVERSITY	1.31	3.22	1.81
EVENNESS INDEX	.27	.67	.38

Fig. B-24. IRI prey spectrum of juvenile walleye pollock in Strait of Juan de Fuca.

Along the Strait of Juan de Fuca, adult threespine stickleback were most common in Beckett Point, Jamestown, and Point Williams beach seine collections. Unlike northern Puget Sound, it was not often encountered in the townet collections. Threespine stickleback appeared to be feeding throughout the nearshore water column, as pelagic calanoid copepods and epibenthic harpacticoid copepods were qually important (Fig. B-27). Limited sample sizes, however, do not allow us to determine whether this catholic feeding beahvior is due to diel changes, site differences or collection methods. Secondary prey organisms were mostly epibenthic forms, including gammarid amphipods and mysids.

Bay Pipefish

Several adult bay pipefish from beach seine collections at Birch Bay were large enough to permit analysis of their stomach contents; 86.8 percent of the total IRI were isopods, the remainder, gammarid amphipods.

Tube-snout

Tube-snouts were frequently captured in the mud/eelgrass and sand/eelgrass habitats and pocket gravel beaches in northern Puget Sound. Common identifiable organisms included gammarid amphipods (90.0 percent of total IRI); only polychaete annelids (6.3 percent), and crab larvae (1.8 percent) were secondary prey. Tube-snouts from beach seine collections along the eastern shoreline, Birch Bay and northeast Guemes Island, tended to have more pelagic organisms in their diet. Pelagic calanoid copepods composed 73.5 percent ofthe total IRI, while harpacticioid copepods (32.1 percent), gammarid amphipods (23.9 percent), and mysids (7.6 percent) made up the principal epibenthic prey composition.

Along the Strait of Juan de Fuca, beach seine and townet collections at Beckett Point and Morse Creek produced numerous tube-snouts. As in the case of threespine stickleback, both calanoid and harpacticoid copepods were the principal prey species of tube-snouts feeding in nearshore habitats (Fig. B-28). Shrimp larvae, though constituting 28.9% of the total prey biomass, were not abundant prey items.

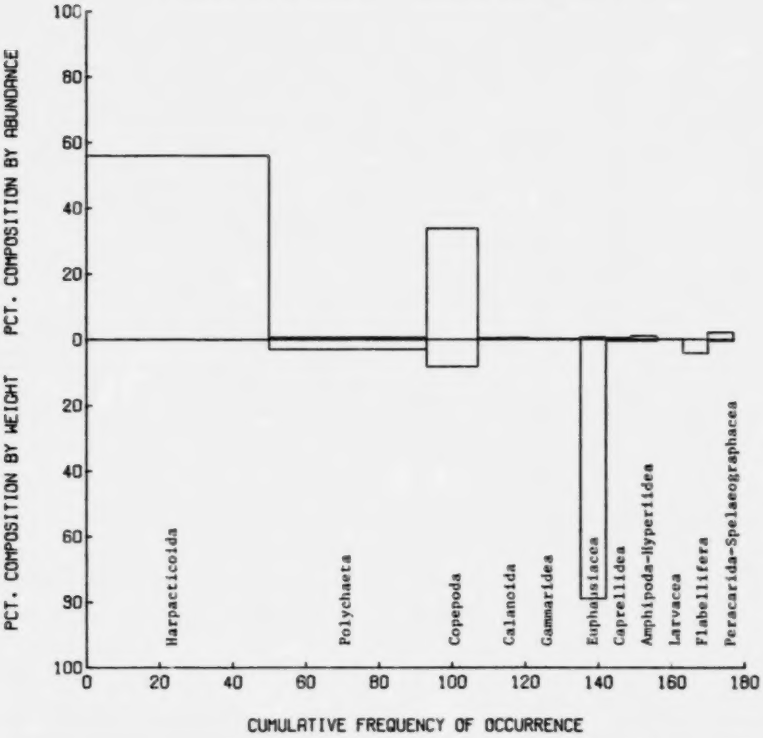
Tube-snout from the Nereocystis kelp beds at Barkley Sound examined by Leaman (1976) had consumed primarily barnacle larvae and caridean crustaceans.

Kelp Greenling

Kelp greenling were the most commonly observed fish in the rocky/kelp bed habitats of northern Puget Sound and often characterized the protected gravel beach enviornments such as those at Deadman Bay and Legoe Bay. The prey spectrum for kelp greenling (Fig. B-29) was one of the most diversified of the species documented. Amphipods, principally Eusiroides sp., Amphithoides sp., ranked as the most important (46.1 percent of total IRI) prey, followed by crabs, Cancer magister, Pugettia gracilis, Oregonia gracilis, Telmessus cheiragonus, and unidentified Oxyrhyncha sp. (5.6 percent), flabelliferan

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD, STATION ALSTA

PREDATOR 8818010101 - GASTEROSTEUS ACULEATUS
(THREESPINE STICKLEBK) ADJUSTED SAMPLE SIZE = 14

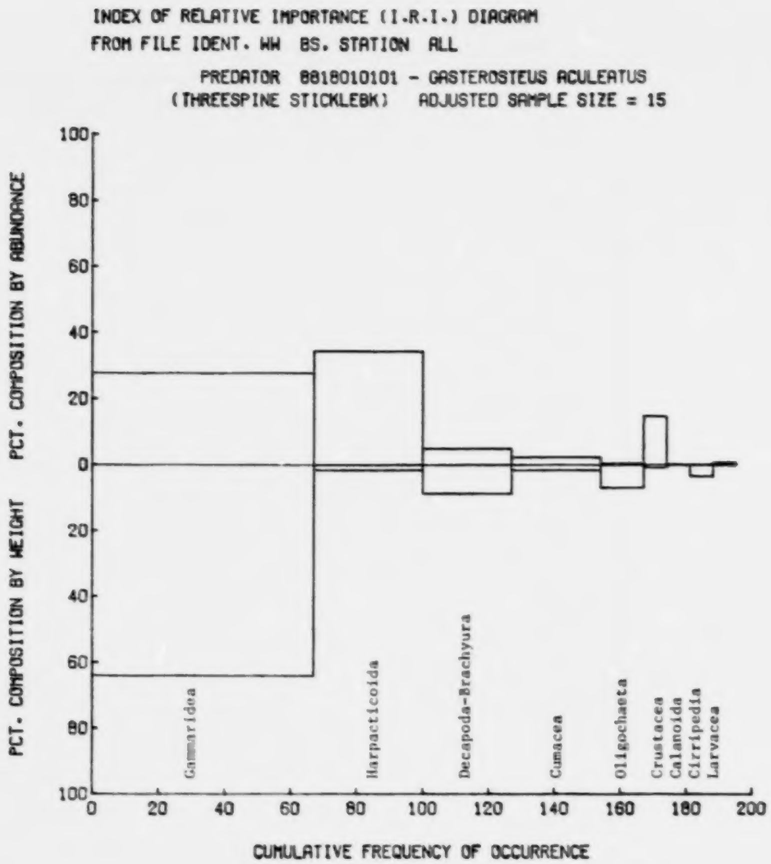


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
HARPACTICOIDA	50.00	55.97	.00	2798.5	67.00
POLYCHAETA	43.00	.65	2.90	152.6	3.70
COPEPODA	14.00	33.77	8.17	594.7	14.20
CALANOIDA	14.00	.47	.00	6.6	.20
GAMMARIDEA	14.00	.19	.00	2.7	.10
EUPHAUSIACEA	7.00	.65	78.84	556.4	13.30
CAPRELLIDEA	7.00	.47	.41	6.2	.10
AMPHIPODA-HYPERIIDEA	7.00	1.03	.41	10.1	.20
LARVACEA	7.00	.09	.00	.6	.00
FLABELLIFERA	7.00	.09	4.15	29.7	.70
PERACARIDA-SPELAEOGRAPHACEA	7.00	2.15	.41	17.9	.40

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.43	.63	.49
SHANNON-WEINER DIVERSITY	1.39	1.00	1.49
EVENNESS INDEX	.40	.36	.45

Fig. B-25. IRI prey spectrum of threespine stickleback from northern Puget Sound.



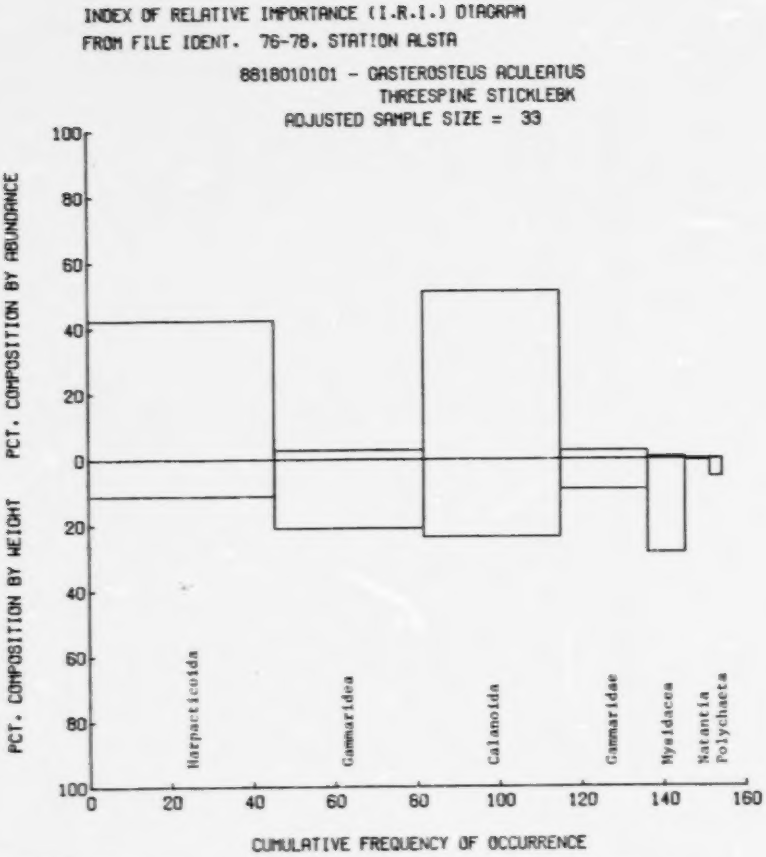
```
                            FREQ   NUM.   GRAV.  PREY     PERCENT
        PREY ITEM           OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
---------------------------  -----  -----  -----  ------  ---------

GAMMARIDEA                   67.00  27.74  64.04  6149.3    76.40
HARPACTICOIDA                33.00  34.35   1.75  1191.3    14.80
DECAPODA-BRACHYURA           27.00   4.84   8.77   367.5     4.60
CUMACEA                      27.00   2.26   1.75   108.3     1.30
OLIGOCHAETA                  13.00    .48   7.02    97.5     1.20
CRUSTACEA                     7.00  14.68    .88   108.9     1.40
CALANOIDA                     7.00    .16    .00     1.1      .00
CIRRIPEDIA                    7.00    .16   3.51    25.7      .30
LARVACEA                      7.00    .65    .00     4.6      .10

  PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
  COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
  (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

     PERCENT DOMINANCE INDEX          .22    .42                .61
     SHANNON-WEINER DIVERSITY        1.90   1.42               1.19
     EVENNESS INDEX                   .60    .51                .40
```

Fig. B-26. IRI prey spectrum of threespine stickleback from shallow sublittoral habitats along the eastern shoreline of northern Puget Sound.

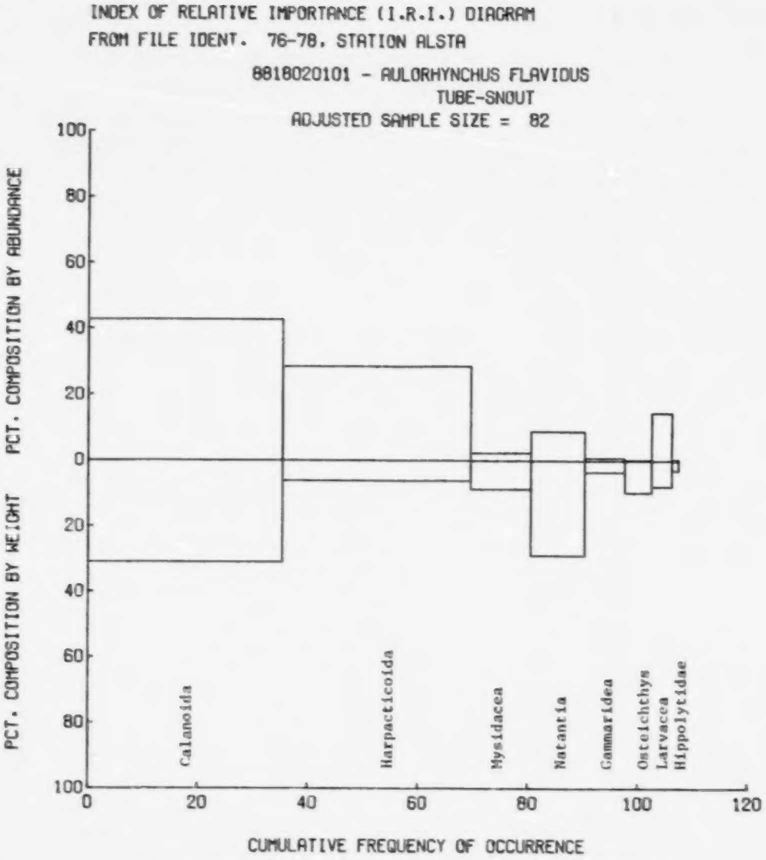


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
HARPACTICOIDA	45.45	42.34	11.13	2430.6	38.47
GAMMARIDEA	36.36	2.81	20.84	859.9	13.61
CALANOIDA	33.33	51.15	23.60	2491.5	39.43
GAMMARIDAE	21.21	2.57	9.15	248.7	3.94
MYSIDACEA	9.09	.65	28.46	264.7	4.19
NATANTIA	6.06	.07	.42	3.0	.05
POLYCHAETA	3.03	.10	5.31	16.4	.26

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.44	.20		.33
SHANNON-WEINER DIVERSITY	1.40	2.49		1.86
EVENNESS INDEX	.40	.72		.54

Fig. B-27. IRI prey spectrum of threespine stickleback from Strait of Juan de Fuca.



```
                                  FREQ   NUM.   GRAV.   PREY    PERCENT
          PREY ITEM               OCCUR  COMP.  COMP.   I.R.I.  TOTAL IRI
 ----------------------------     -----  -----  -----   ------  ---------

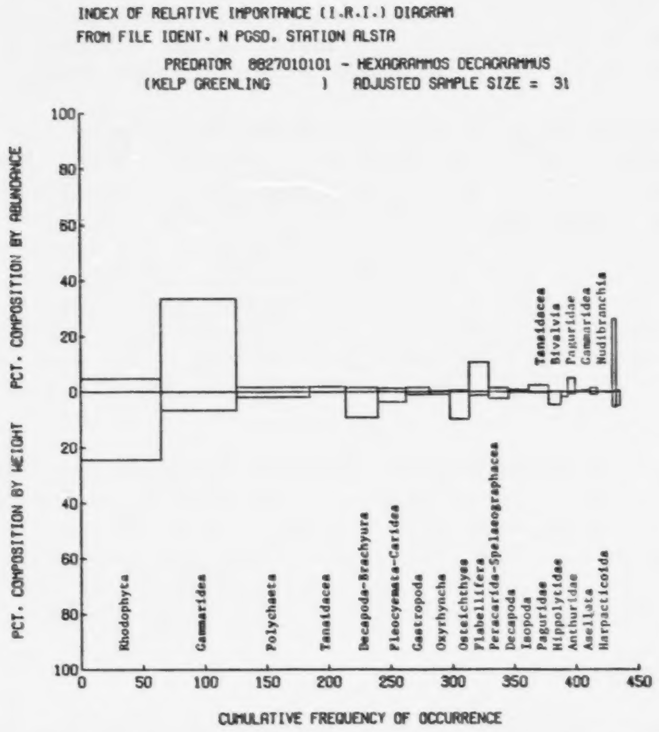
CALANOIDA                         35.37  42.78  30.92   2606.5    58.53
HARPACTICOIDA                     34.15  28.59   6.11   1184.7    26.60
MYSIDACEA                         10.98   2.34   8.64    120.5     2.71
NATANTIA                           9.76   8.85  28.89    368.2     8.27
GAMMARIDEA                         7.32    .82   3.47     31.5      .71
OSTEICHTHYS                        4.88    .26   9.73     48.7     1.09
LARVACEA                           3.66  14.53   7.84     81.9     1.84
HIPPOLYTIDAE                       1.22    .35   2.98      4.1      .09

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX              .29    .21                .42
      SHANNON-WEINER DIVERSITY            2.11   2.65               1.65
      EVENNESS INDEX                       .55    .70                .43
```

Fig. B-28. IRI prey spectrum of tube-snout in Strait of Juan de Fuca.

Reproduced from best available copy.


INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD. STATION ALSTA
PREDATOR 8827010101 - HEXAGRAMMOS DECAGRAMMUS
(KELP GREENLING) ADJUSTED SAMPLE SIZE = 31

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
RHODOPHYTA	65.00	4.78	24.46	1900.6	33.90
GAMMARIDEA	61.00	33.39	6.61	2440.0	4.40
POLYCHAETA	59.00	1.70	1.88	211.2	3.80
TANAIDACEA	29.00	1.79	.08	54.2	1.00
DECAPODA-BRACHYURA	26.00	1.49	9.20	277.9	5.00
PLEOCYEMATA-CARIDEA	23.00	1.17	3.66	11.1	.20
GASTROPODA	19.00	1.47	.99	46.7	.80
OXYRHYNCHA	16.00	.21	1.01	19.5	.30
OSTEICHTHYES	16.00	.50	9.79	104.6	1.90
FLABELLIFERA	16.00	10.58	1.29	189.9	3.40
PERACARIDA-SPELAEOGRAPHACEA	16.00	1.35	2.47	61.1	1.10
DECAPODA	16.00	.62	.28	14.4	.30
ISOPODA	16.00	2.32	.37	43.0	.80
PAGURIDAE	10.00	.12	4.68	48.0	.90
HIPPOLYTIDAE	6.00	.09	1.77	11.2	.20
ANTHURIDAE	6.00	4.93	.70	33.8	.60
ASELLOTA	6.00	.23	.00	1.4	.10
HARPACTICOIDA	6.00	.50	.00	3.0	.10
TANAIDACEA	6.00	1.26	1.03	13.7	.20
BIVALVIA	6.00	.09	.05	.8	.00
PAGURIDAE	6.00	.06	.31	2.2	.10
GAMMARIDEA	3.00	26.06	5.46	94.6	1.70
NUDIBRANCHIA	3.00	.41	4.94	16.0	.30

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.20	.09	.12
SHANNON-WEINER DIVERSITY	2.79	2.99	2.01
EVENNESS INDEX	.61	.68	.45

Fig. B-29. IRI prey spectrum of kelp greenling in northern Puget Sound.

isopods (34 percent) fishes (1.9 percent), polychaetes (3.7 percent), gastropods (3.5 percent), and tanaids (1.2 percent). Although algae (Rhodophyta 33.9 percent), constituted a measurable percentage of the total biomass, these were considered incidental items, byproducts of the feeding of kelp greenling on the predominantly benthic prey items.

The only food data for kelp greenling in the Strait of Juan de Fuca, that from Leaman's (1976) collections at Barkley Sound, Vancouver Island, indicated that caprellid (*Caprella gracilion*, *C. laeviscula*, *C. ferrea*, *C. incisa*, and *C. equilibra*) and gammarid amphipods (*Parapleustes pugettensis*, *Erichtonius brasiliensis*, *Photis* sp., *Podocerus* sp., *Metaphoxis* sp.) were the most important prey; fish (*Artedius lateralis*, *Synchirus gilli*), crabs (*Pachycheles* sp., *Cancer gracilis*, *C. oregonensis*, *Pagurus* sp., *Oregonia gracilis*, *Loxorhynchus crispatus*, *Petrolistes eriomerus*) and shrimp (*Heptacarpus* sp.) were of secondary importance. The diet of greenling between 101-200 mm in length was dominated by isopods while that between 201-700 mm was prevalently crabs.

Juvenile kelp greenling were reported by Barraclough and his co-workers to be one of the most common fishes in the neritic waters of the Strait of Georgia in May-June (Barraclough 1967 a, b, & c; Robinson et al. 1968 a & b). Calanoid copepods (*Calanus plumchrus*, *Pseudocalanus minutus*), cladocerans (*Podon* sp.) hyperiid amphipods (*Parathemisto pacifica*) and larval fish (eulachon) were important prey taxa at this stage (Table B-3).

Whitespotted Greenling

In northern Puget Sound adult whitespotted greenling was collected most often at pocket gravel beaches such as at Deadman Bay during beach seining. It was also collected in the rocky/kelp bed habitat, but in much smaller numbers than the kelp greenling.

The prey spectrum of the whitespotted greenling was very similar to the kelp greenling (Fig. B-30). Gammarid amphipods, especially *Eusiroides* sp., *Amphithoe* sp., constituted the most important food item, contributing 55.7 percent of the total IRI. Shrimp (*Heptacarpus stimpsoni*), with 22.4 percent, and various brachyuran crabs (*Cancer oregonensis*, *Pugettia gracilis*), with 11.4 percent of the total IRI, were secondary; fish and polychaete annelids provided less than 5 percent each. Incidental algae, however, was not as significant in the overall diet composition ofthe whitespotted greenling as the kelp greenling. Whitespotted greenling were often collected during beach seine sampling at northeastern Guemes Island, Birch Bay, Cherry Point and Legoe Bay along the eastern shoreline. Despite the different areas and habitats, prey composition of this sample was very similar to those from San Juan Island collections, with gammarid amphipods responsible for 65.9 percent of the total IRI; penaeid and callianassid shrimp, 21.6 percent; brachyuran crabs, 10.0 percent, and polychaetes, 1.3 percent (Fig. B-31).

Along the Strait of Juan de Fuca, whitespotted greenling, most of which were juveniles, were included in beach seine collections at Beckett Point and Point Williams. The overall prey spectrum of whitespotted greenling

Table B-3. Prey composition table for juvenile kelp greenling in neritic waters of Strait of Georgia, documented by Barraclough (1967a).

```
PREDATOR  8827010101 - HEXAGRAMMOS DECAGRAMMUS                   (KELP GREENLING       )

                   INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                     FROM FILE IDENT. REF  1. STATION ALSTA
                   ******************************************

                                              FREQ   NUM.   GRAV.  PREY     PERCENT
            PREY ITEM                         OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   ---------------------------                -----  -----  -----  ------  ---------

   CALANOIDA                                  98.90  97.50
   AMPHIPODA                                   5.40   1.00
   OSTEICHTHYES                                3.30    .30
   EUPHAUSIACEA                                2.20    .10
   CRUSTACEA                                   2.20   1.00
   THERAGRA CHALCOGRAMMA                       1.10    .10
   OIKOPLEURA SP.                              1.10    .10

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

         PERCENT DOMINANCE INDEX                     .95    .00                 .00
         SHANNON-WEINER DIVERSITY                    .22   -.00                -.00
         EVENNESS INDEX                              .08    .00                 .00
```

```
INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD, STATION ALSTA
                  PREDATOR  8827010104 - HEXAGRAMMOS STELLERI
               (WHITESPOT GREENLING )   ADJUSTED SAMPLE SIZE =  13
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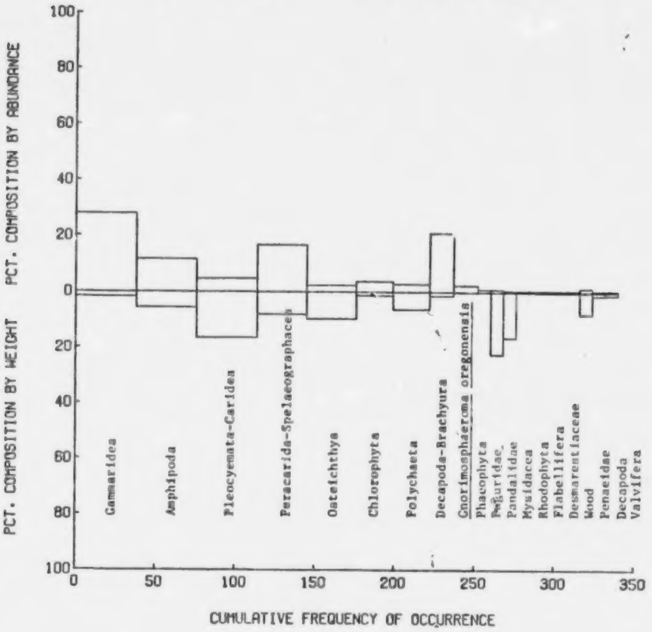

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                                  FREQ   NUM.   GRAV.   PREY    PERCENT
        PREY ITEM                 OCCUR  COMP.  COMP.   I.R.I.  TOTAL IRI
 ---------------------------      -----  -----  -----   ------  ---------

 GAMMARIDEA                       38.00  27.91   1.74   1126.7    23.10
 AMPHIPODA                        38.00  11.63   5.67    657.4    13.50
 PLEOCYEMATA-CARIDEA              38.00   4.65  16.54    805.2    16.50
 PERACARIDA-SPELAEOGRAPHACEA      31.00  16.74   8.04    768.2    15.80
 OSTEICHTHYES                     31.00   2.34   9.69    372.9     7.60
 CHLOROPHYTA                      23.00   3.72   1.26    114.5     2.30
 POLYCHAETA                       23.00   2.79   6.26    208.1     4.30
 DECAPODA-BRACHYURA               15.00  20.93   1.42    335.2     6.90
 GNORIMOSPHAEROMA OREGONENSIS     15.00   2.33    .23     38.4      .80
 PHAEOPHYTA                        8.00    .93    .07      8.0      .00
 PAGURIDAE                         8.00    .93  22.46    187.1     3.80
 PANDALIDAE                        8.00    .47  16.37    134.7     2.80
 MYSIDACEA                         8.00    .47    .00      3.8      .00
 RHODOPHYTA                        8.00    .47    .03      4.0      .00
 FLABELLIFERA                      8.00    .47    .00      3.8      .00
 DESMARESTIACEAE                   8.00    .47    .10      4.6      .00
 WOOD                              8.00    .47    .04      4.1      .00
 PENAEIDAE                         8.00   1.40   7.86     74.1     1.50
 DECAPODA                          8.00    .47   1.20     13.4      .30
 VALVIFERA.                        8.00    .47   1.01     11.8      .20

    PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
    COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
    (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

       PERCENT DOMINANCE INDEX             .17    .13               .14
       SHANNON-WEINER DIVERSITY           3.06   3.19              3.11
       EVENNESS INDEX                      .71    .77               .82
```

Fig. B-30. IRI prey spectrum of whitespotted greenling in northern Puget Sound.

```
INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. WW  BS. STATION  ALL
          PREDATOR  8827010104 - HEXAGRAMMOS STELLERI
        (WHITESPOT GREENLING )   ADJUSTED SAMPLE SIZE = 13
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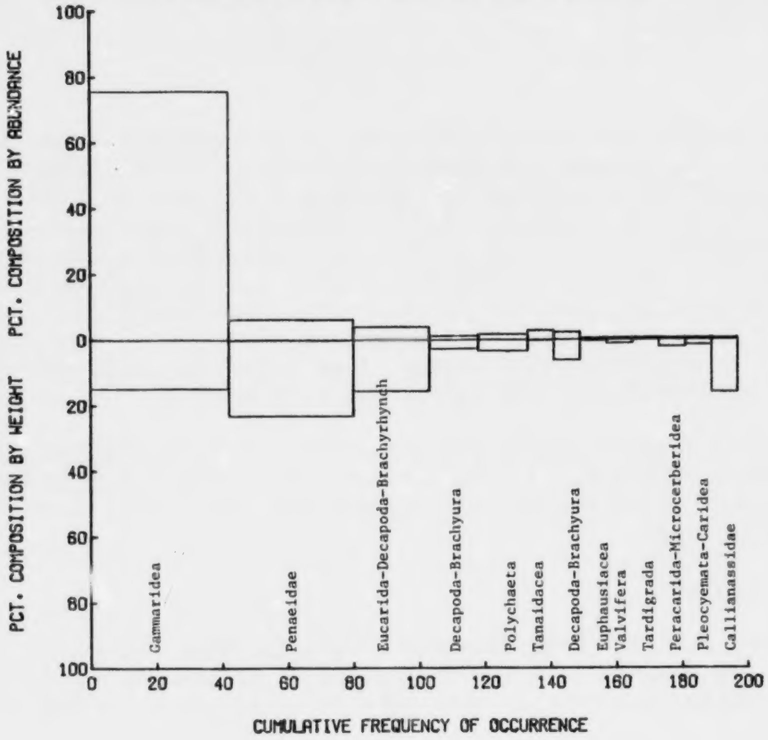


```
                                   FREQ   NUM.   GRAV.  PREY     PERCENT
         PREY ITEM                 OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
 ----------------------------      -----  -----  -----  ------  ---------

GAMMARIDEA                         42.00  75.70  14.83  3802.2    65.90
PENAEIDAE                          38.00   6.21  23.12  1114.5    19.30
EUCARIDA-DECAPODA-BRACHYRHYNCH     23.00   3.95  15.60   449.6     7.80
DECAPODA-BRACHYURA                 15.00   1.13   2.83    59.4     1.00
POLYCHAETA                         15.00   1.69   3.49    77.7     1.30
TANAIDACEA                          8.00   2.82    .22    24.3      .40
DECAPODA-BRACHYURA                  8.00   2.26   6.24    68.0     1.20
EUPHAUSIACEA                        8.00    .56    .35     7.1      .10
VALVIFERA                           8.00    .56   1.10    13.3      .20
TARDIGRADA                          8.00    .56    .06     5.0      .00
PERACARIDA-MICROCERBERIDEA          8.00    .56   2.20    22.1      .40
PLEOCYEMATA-CARIDEA                 8.00    .56   1.69    18.0      .30
CALLIANASSIDAE                      8.00    .56  15.97   132.2     2.30

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX               .58    .13                .48
      SHANNON-WEINER DIVERSITY             1.43   2.65               1.61
      EVENNESS INDEX                        .39    .72                .45
```

Fig. B-31. IRI spectrum of whitespotted greenling in shallow sublittoral habitats along the eastern shoreline in northern Puget Sound.

was one of the most diverse encountered. Gammarid amphipods were the most important prey (60.9% of total IRI) but tanaids, polychaete annelids, hippolytid shrimp (Heptacarpus sp.), crangonid shrimp, bivalves and bivalve siphons, and majid and pagurid crabs all composed more than 1% of the total IRI (Fig. B-32).

Lingcod

The lingcod was commonly observed in rocky/kelp bed habitats of northern Puget Sound (57 percent frequency of occurrence during SCUBA transect observations) and consituted the major top-level carnivore in the fish assemblage characterizing that habitat. Stomach contents examined from eight adults and six juveniles indicated that lingcod were primarily piscivorous, with 36.1 percent of the total IRI being fish. Although the fish were usually digested beyond recognition, rockfish (Scorpaenidae) were identified. The remaining secondary food items were benthic gastropods, siphonophores, ascidians, polychaetes, and incidental algae. Except for the fish, which may or may not be bottom-oriented, all the prey items were benthic.

Lingcod sampled during Quast's (1968) detailed examination of southern California's kelp bed fish communities had consumed predominantly fishes (Perciformes, Clupeiformes) while algae and cephalopods were less representative prey (Table B-4).

Copper Rockfish

Copper rockfish were commonly caught in beach seine collections in northern Puget Sound during July and August at Deadman Bay (gravel habitat) and were frequently sighted along all SCUBA transects in the rocky/kelp bed habitat.

The composite prey spectrum (Fig. B-33) suggests that copper rockfish were facultative epibenthic feeders, having consumed both benthic and pelagic organisms. General percaridan crustaceans were the more important prey; these included gammarid amphipods (40.3 percent of total IRI), mysids (6.0 percent), shrimp (3.0 percent) brachyuran crabs (Cancer gracilis, Petrolistes eriomerus and Scyra acutifrons, 1.9 percent), flabelliferan (4.9 percent) isopods, and cumaceans (1.4 percent). Fish (Pacific sand lance and juvenile rockfish) accounted for 17.6 percent of the total IRI.

Juvenile copper rockfish sampled by beach seine along the eastern shoreline (Legoe Bay) had a relatively similar diet composition based on epibenthic and pelagic prey. Shrimp (Crangonidae, Pandalidae, and Penaeidae) and gammarid amphipods predominated, with 36.1 percent and 31.8 percent, respectively, of the total IRI. Crab larvae (15.9 percent) and fish (threespine stickleback, 13.7 percent) formed secondary diet components.

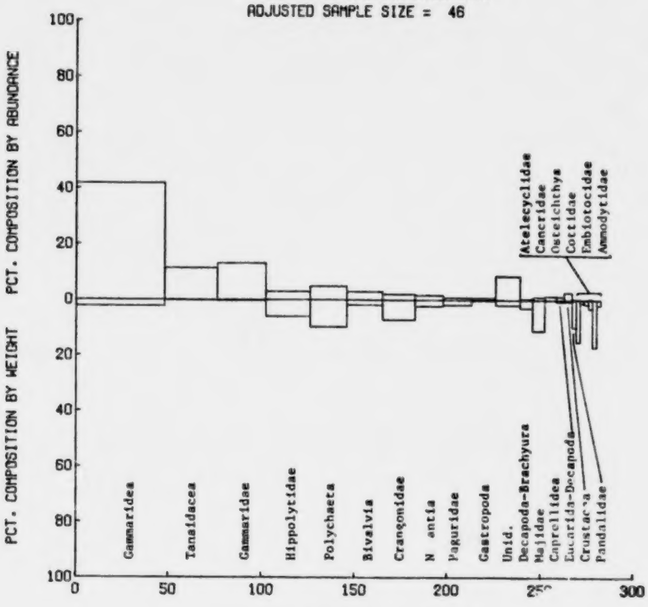
Copper rockfish were too rare in the Strait of Juan de Fuca collections to be includedin the food web data base.

Table B-4. Prey composition (frequency of occurrence) of lingcod in southern California kelp beds documented by Quast (1968).

```
PREDATOR  8827010201 - OPHIODON ELONGATUS                    (LINGCOD            )


              INDEX OF RELATIVE IMPORTANCE (I.P.I.) TABLE
                FROM FILE IDENT. REF 59. STATION SLSTA
              ******************************************

                                      FREQ   NUM.   GRAV.  PREY     PERCENT
            PREY ITEM                 OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  ----------------------------        -----  -----  -----  ------  ---------

 PERCIFORMES                          49.00
 CLUPEOMORPHA CLUPEIFORMES            19.00
 TELEOSTEI                            12.00
 UNIDENTIFIED ALGAE                   11.00
 THEUTHIDIDA                           6.00

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                .00    .00              .00
      SHANNON-WEINER DIVERSITY               .00    .00              .00
      EVENNESS INDEX                         .00    .00              .00
```

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA

8827010104 - HEXAGRAMMOS STELLERI
WHITESPOT GREENLING
ADJUSTED SAMPLE SIZE = 46



CUMULATIVE FREQUENCY OF OCCURRENCE

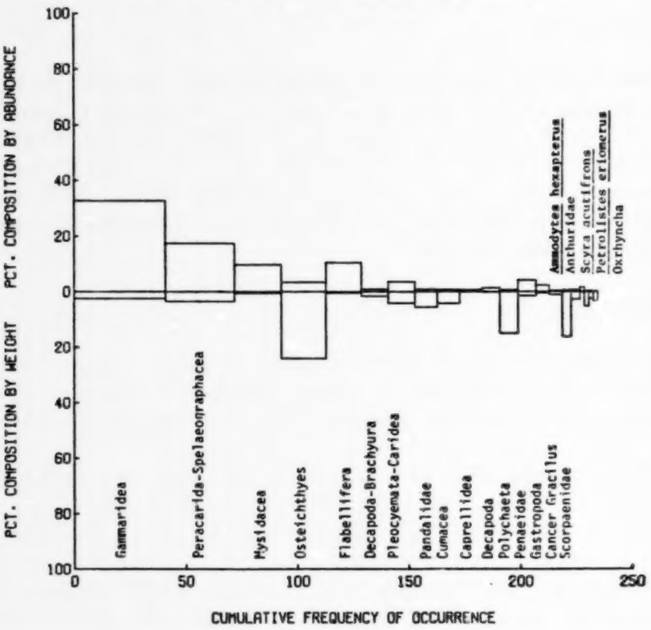
PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	47.83	41.86	2.34	2114.0	52.28
TANAIDACEA	28.26	11.32	.17	324.7	8.03
GAMMARIDAE	26.09	12.98	.33	347.0	8.58
HIPPOLYTIDAE	23.91	2.93	6.09	215.6	5.33
POLYCHAETA	19.57	4.83	9.81	286.6	7.09
BIVALVIA	19.57	2.93	1.86	93.7	2.32
CRANGONIDAE	17.39	2.04	7.19	160.5	3.97
NATANTIA	15.22	1.65	2.34	60.8	1.50
PAGURIDAE	15.22	.89	1.87	42.0	1.04
GASTROPODA	13.04	.76	.25	13.3	.33
UNIDENTIFIED	13.04	8.52	1.94	136.6	3.38
DECAPODA-BRACHYURA	6.52	.38	2.94	21.7	.54
MAJIDAE	6.52	1.02	11.16	79.4	1.96
CAPRELLIDEA	6.52	1.27	.13	9.1	.23
EUCARIDA-DECAPODA	4.35	1.15	.66	7.9	.19
CRUSTACEA	4.35	2.67	.59	14.1	.35
PANDALIDAE	2.17	.25	9.84	21.9	.54
ATELECYCLIDAE	2.17	.25	15.06	33.1	.82
CANCRIDAE	2.17	.13	1.11	2.7	.07
OSTEICHTHYS	2.17	.13	1.58	3.7	.09
COTTIDAE	2.17	.38	3.18	7.7	.19
EMBIOTOCIDAE	2.17	.13	16.96	37.1	.92
AMMODYTIDAE	2.17	.13	1.92	4.5	.11

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.22	.10		.30
SHANNON-WEINER DIVERSITY	3.03	3.77		2.69
EVENNESS INDEX	.63	.78		.56

Fig. B-32. IRI prey spectrum of whitespotted greenling in shallow sublittoral habitats along Strait of Juan de Fuca.

Reproduced from best available copy.



INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD, STATION ALSTA
PREDATOR 8826010108 - SEBASTES CAURINUS
(COPPER ROCKFISH) ADJUSTED SAMPLE SIZE = 52

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                                  FREQ   NUM.   GRAV.  PREY     PERCENT
         PREY ITEM                OCCUR  COMP.  COMP.  I.R.I.   TOTAL IRI
 ------------------------------   -----  -----  -----  ------   ---------

 GAMMARIDEA                       41.00  32.74   2.45  1442.8     40.30
 PERACARIDA-SPELAEOGRAPHACEA      31.00  17.45   3.49   649.1     18.10
 MYSIDACEA                        21.00   9.73    .51   215.0      6.00
 OSTEICHTHYES                     20.00   3.41  24.00   548.2     15.30
 FLABELLIFERA                     16.00  10.50    .46   175.4      4.90
 DECAPODA-BRACHYURA               12.00    .89   1.58    29.6       .80
 PLEOCYEMATA-CARIDEA              12.00   3.54   4.04    91.0      2.50
 PANDALIDAE                       10.00    .88   5.55    64.3      1.80
 CUMACEA                          10.00    .76   4.20    49.6      1.40
 CAPRELLIDEA                      10.00    .63    .08     7.1       .20
 DECAPODA                          8.00   1.26    .22    11.9       .30
 POLYCHAETA                        8.00    .51  15.01   124.2      3.50
 PENAEIDAE                         8.00   4.05   1.44    43.9      1.20
 GASTROPODA                        6.00   2.28    .45    16.4       .50
 CANCER GRACILUS                   6.00    .38   1.07     8.7       .20
 SCORPAENIDAE                      4.00    .51  16.11    66.5      1.90
 AMMODYTES HEXAPTERUS              4.00    .63   2.75    13.5       .40
 ANTHURIDAE                        2.00   1.52    .11     3.3       .10
 SCYRA ACUTIFRONS                  2.00    .13   5.17    10.6       .30
 PETROLISTHES ERIOMERUS            2.00    .25   2.38     5.3       .10
 OXRHYNCHA                         2.00    .13   3.34     6.9       .20

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX              .16    .12                .23
      SHANNON-WEINER DIVERSITY            2.88   3.30               2.77
      EVENNESS INDEX                       .65    .75                .63
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Fig. B-33. Spectrum of copper rockfish from northern Puget Sound.

Prince and Gotshaul (1978) documented the prey spectrum of 241 copper rockfish captured around an artificial reef in South Humbolt Bay, California. In terms of frequency of occurrence and percent volume, juvenile Cancer magister dominated the diet (40% of total IRI) while gammarid amphipods composed 31% of the total number of prey items. Crangonid shrimp, caprellid amphipods and northern anchovy provided secondary food items.

Puget Sound Rockfish

Puget Sound rockfish were documented only during SCUBA transect observations in the rocky/kelp bed habitats along San Juan channel (Pt. George, Shaw Is.). The overall prey composition indicated a relatively unspecialized planktonic feeding behavior. Calanoid copepods (57.3 percent of total IRI), siphonophores (17.8 percent), and crab larvae (16.0 percent) constituted the more important prey; hyperiid amphipods (5.1 percent), and crabs (1.6 percent) were secondary in importance.

Yellowtail Rockfish

Although juvenile yellowtail rockfish were often caught in the beach seine sampling at Deadman Bay in northern Puget Sound, the majority originated from rocky/kelp bed habitats around San Juan Island and Burrows Island.

Prey composition, similar to those of Puget Sound rockfish, emphasized pelagic organisms. Calanoid copepods accounted for the highest proportion (34.4 percent) of the total IRI while mysids (20.1 percent, Neomysis awatchensis)*, fishes (17.5 percent including Pacific sand lance), crab larvae (10.6 percent), chaetognaths (8.4 percent), hyperiid amphipods (2.1 percent), and fish larvae (1.2 percent) composed the other food items. Gammarid amphipods (including Pontogeneia sp., and Eusiroides sp., Atylus sp., Ischyrocerus sp., and Photis californicus) were not very important.

Black Rockfish

Adult black rockfish constituted over 15 percent of the total fish enumerated along the SCUBA transects in northern Puget Sound. Prey organisms were predominantly pelagic organisms. Hyperiid amphipods (79.9 percent of total IRI) were most important, followed by fishes (13.9 percent; including Pacific sand lance and tadpole sculpins), crab larvae (1.1 percent), and crabs (1.0 percent; Cancer sp.). Incidental items such as rocks accounted for 1.7 percent of the total IRI. Gammarid amphipods (predominantly Eusiroides sp., Pontogeneia spp., and Atylus sp., but also Ischyrocerus sp., Hyale sp., Paraphoxus spinosa (?), Photis californica, Photis sp., Amphithoe lacertosa, and Amphithoe sp.) were not significant in the total IRI.

Juvenile black rockfish from shallow sublittoral gravel habitats at Deadman Bay and Guemes Island had an entirely different diet composition which emphasized epibenthic prey such as shrimp, harpacticoid copepods, and gammarid amphipods.

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*Holmquist (1973) suggests that N. awatchensis should be considered as N. mercedis in the Northeast Pacific. We have, however, left it as N. awatchensis to minimize confusion.

Scalyhead Sculpin

Scalyhead sculpins were the second most common cottid observed in the rocky/kelp bed SCUBA observations in the vicinity of San Juan Island. The few specimens which were procured by slurp gun or spearing indicated a diverse array of organisms--pelagic, epibenthic, and benthic--were included in its diet. Harpacticoid copepods were the most important prey. Chaetognaths (pelagic arrow worms), calanoid copepods, crabs (*Petrolisthes eriomerus*), crab larvae, mysids, shrimps, gammarid and hyperiid amphipods, fishes, euphausiids, and caprellid amphipods were of secondary importance.

Caprellid amphipods (*Caprella mendax*, *C. laeviscula*, *C. equilibra*, *C. natalensis*, *C. incisa*, *C. guacilior*, *C. ferrez*, *Metacaprella kennerlyi*) and tammarid amphipods (*Photis californica*, *P. bifurcata*, *Parapleustes pugettensis*, *Podocerus* sp., *Erichtonius brasiliensis*, *Lembos* sp.) and shrimp (*Heptacarpus* sp.) were listed as prey of scalyhead sculpins collected in *Nereocystis* kelp beds on the outer coast of Vancouver Island (Leaman 1976).

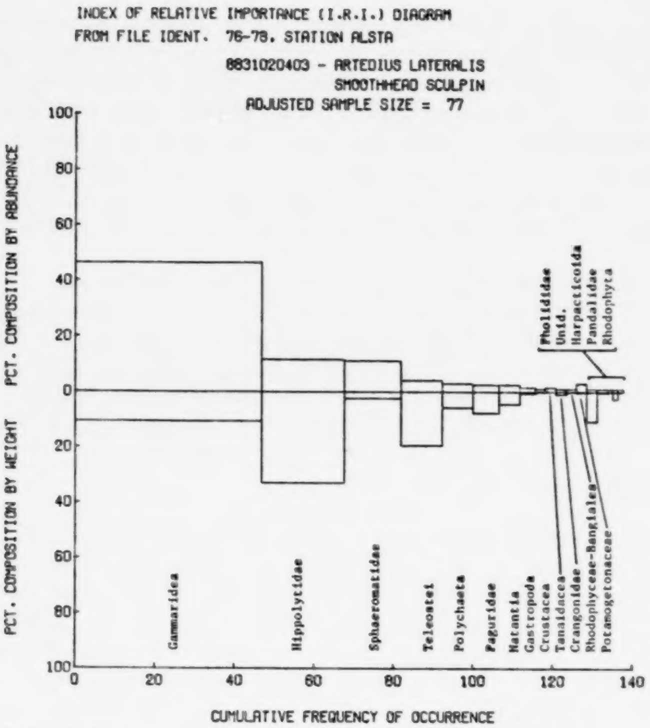
Smoothhead Sculpin

Smoothhead sculpins were not common in beach seine collections in either northern Puget Sound or along the Strait of Juan de Fuca. They appeared in almost all the tidepool collections along the strait and were especially common at Observatory Point and Slip Point. Gammarid amphipods and hippolytid shrimp together formed 84.0% of the total IRI. Fish (including *Pholis* sp.), sphaeromatid isopods (including *Gnorimosphaeroma oregonensis*, *Exosphaeroma amplicauda*, and *Dynamenella sheareri*), polychaete annelids, and pagurid (hermit) crabs (including *Pagurus beringanus*) were of secondary importance (Fig. B-34).

Leaman's (1976) collections of smoothhead sculpins in the *Nereocystis* kelp beds in Barkley Sound, outer Vancouver Island, indicated that amphipods (caprellids, *Caprella equilibra*, *C. incisa* and gammarids, *Photis bifurcata*, *P. californica*) composed the highest proportion of the prey, followed by shrimp (*Betaeus setosus*, *Lebbeus lagunae*), crabs (*Pachycheles* sp., *Podocerus* sp.) and fish (northern clingfish, longfin sculpin).

Rosylip Sculpin

While not found abundantly during the DOE studies in northern Puget Sound, rosylip sculpins were ubiquitously distributed among the intertidal collection sites along the Strait of Juan de Fuca. In that region gammarid amphipods (67.8% of total IRI) and sphaeromatid isopods (including *Gnorimosphaeroma oregonensis*, *Exosphaeroma amplicauda*, and *Dynamenella sheareri*; 20.8%) composed the majority of the IRI prey spectrum (Fig. B-35). Idoteid isopods (including *Idotea wosnesenski*), polychaete annelids, crustacean larvae, and mysids (including *Archaeomysis grebnitzki*) composed most of the remaining important prey organisms.

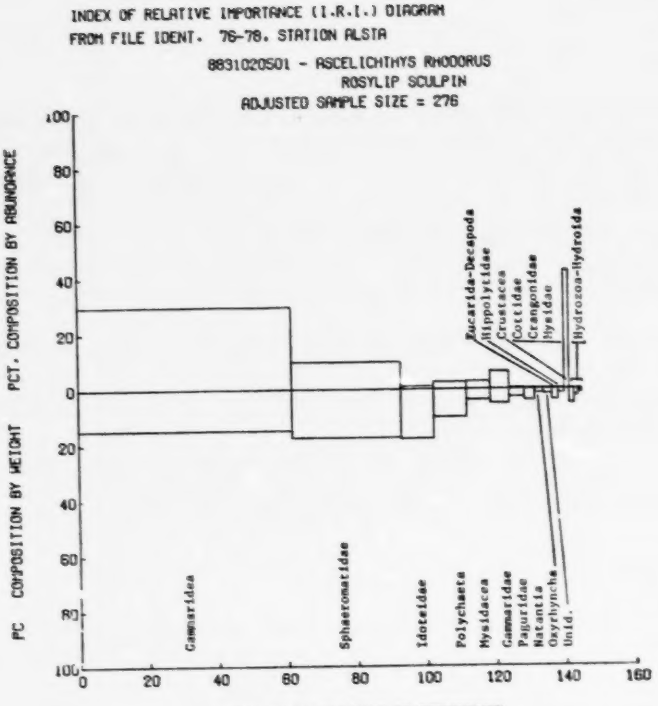


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	46.75	46.46	10.69	2672.2	62.37
HIPPOLYTIDAE	20.78	11.62	32.91	925.1	21.59
SPHAEROMATIDAE	14.29	11.11	2.42	193.3	4.51
TELEOSTEI	10.39	4.04	19.37	243.2	5.68
POLYCHAETA	7.79	3.03	5.70	68.0	1.59
PAGURIDAE	6.49	2.53	7.66	66.2	1.54
NATANTIA	5.19	2.53	4.47	36.4	.85
GASTROPODA	3.90	1.52	.53	8.0	.19
CRUSTACEA	2.60	1.01	.08	2.8	.07
TANAIDACEA	2.60	1.52	.02	4.0	.09
CRANGONIDAE	2.60	1.01	.94	5.1	.12
RHODOPHYCEAE-BANGIALES	2.60	1.01	.04	2.7	.06
POTAMOGETONACEAE	2.60	3.03	.25	8.5	.20
PHOLIDIDAE	2.60	1.01	10.80	30.7	.72
UNIDENTIFIED	2.60	1.01	.25	3.3	.08
HARPACTICOIDA	1.30	1.01	.00	1.3	.03
PANDALIDAE	1.30	1.01	2.64	4.7	.11
RHODOPHYTA	1.30	1.01	.02	1.3	.03

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.25	.18		.44
SHANNON-WEINER DIVERSITY	3.05	2.93		1.75
EVENNESS INDEX	.64	.62		.37

Fig. B-34. IRI prey spectrum of smoothhead sculpin in littoral beaches along the Strait of Juan de Fuca.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	61.59	29.66	14.76	2735.9	66.32
SPHAEROMATIDAE	31.52	9.87	17.33	857.2	20.78
IDOTEIDAE	9.42	1.01	17.76	176.9	4.29
POLYCHAETA	9.42	2.54	10.07	118.9	2.88
MYSIDACEA	6.88	2.73	3.93	45.9	1.11
GAMMARIDAE	5.43	6.20	5.21	62.0	1.50
PAGURIDAE	4.35	.37	2.89	14.2	.34
NATANTIA	2.90	.28	3.98	12.4	.30
OXRHYNCHA	2.54	.23	1.53	4.4	.11
UNIDENTIFIED	2.54	.25	1.72	5.0	.12
EUCARIDA-DECAPODA	1.81	.23	3.87	7.4	.18
HIPPOLYTIDAE	1.81	.17	1.55	3.1	.08
CRUSTACEA	1.45	42.37	.15	61.6	1.49
COTTIDAE	1.45	.11	5.23	7.7	.19
CRANGONIDAE	1.09	.08	2.47	2.8	.07
MYSIDAE	.72	.23	1.29	1.1	.03
HYDROZOA-HYDROIDA	.36	.03	1.31	.5	.01

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.28	.11		.49
SHANNON-WEINER DIVERSITY		2.49	3.75		1.61
EVENNESS INDEX		.44	.66		.28

Fig. B-35. IRI prey spectrum of rosylip sculpin in littoral habitats along Strait of Juan de Fuca.

Caprellid (Caprella incisa, C. equilibra) and gammarid amphipods (Parapleustes pugettensis, Advoides sp.) were the principal prey of rosylip sculpins in the Nereocystis kelp bed habitat in Barkley Sound, outer Vancouver Island (Leaman 1976).

Padded Sculpin

Principal prey of padded sculpins from northern Puget Sound were gammarid amphipods (89.1 percent of total IRI) and several other epibenthic crustaceans--the flabelliferan isopod (Gnorimosphaeroma oregonense) (6.5 percent) and tanaids (3.0 percent). In these collections from the eastern shoreline (i.e., Legoe Bay) gammarid amphipods also were the most prevalent prey (88.7 percent of total IRI), followed by unidentified Caridean crustaceans (shrimp; 5.7 percent), and sphaeromatid isopods (3.7 percent) (Fig. B-36).

In the Strait of Juan de Fuca padded sculpin were common at Twin Rivers and Beckett Point, and were especially abundant in winter. Epibenthic crustaceans--gammarid (including Corophiidae) amphipods, hippolytid shrimp (Heptacarpus kincaidi, H. tenuissimus), crangonid shrimp, sphaeromatid isopods (Gnorimosphaeroma oregonensis and Exosphaeroma amplicauda), and idoteid isopods (Synidotea sp. and Idotea wosnesenski)--were more abundant than benthic prey organisms such as polychaetes (Fig.B-37).

Silverspotted Sculpin

In northern Puget Sound silverspotted sculpin commonly appeared in the pocket gravel beach habitat (Deadman Bay) beach seine collections from July through October. The spectrum of prey identified from these specimens was oriented toward epibenthic crustaceans, specifically gammarid amphipods (40.1 percent of total IRI; including Amphithoe sp.). flabelliferan isopods (39.6 percent) and shrimp (9.6 percent; Heptacarpus stimpsoni) (Fig. B-38).

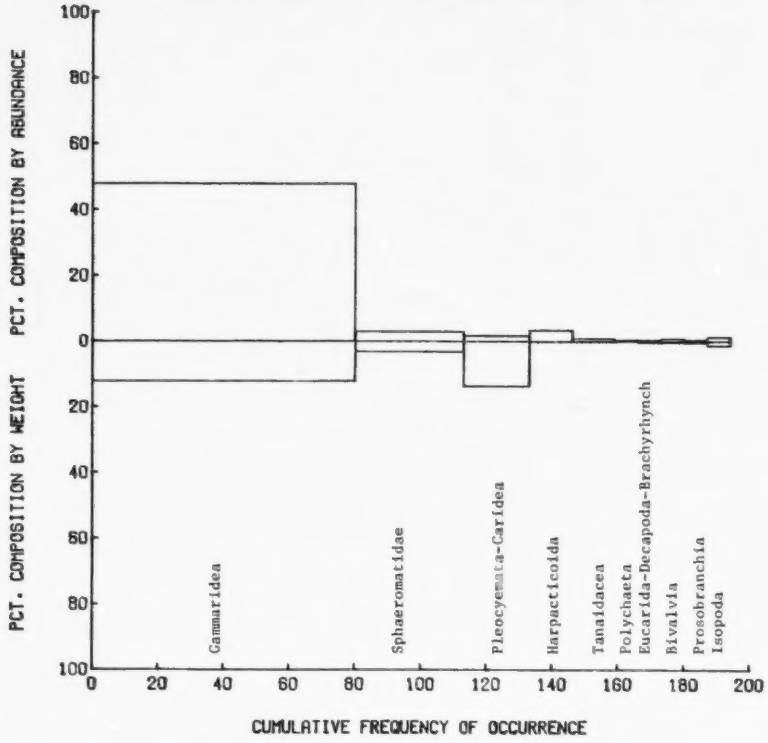
Silverspotted sculpin specimens from cobble and gravel habitat sites at Cherry Point, Shannon Point, and Legoe Bay appeared to be even more specialized in their diet. Gammarid amphipods were 32.7 percent of the total IRI, shrimp 7.2 percent.

Of the sites sampled along the Strait of Juan de Fuca, beach seine collections at Twin Rivers, Morse Creek, and Jamestown generally provided the most silverspotted sculpin. The prey spectrum (Fig. B-39) was almost evenly divided between mysids and gammarid amphipods.

Roughback Sculpin

Roughback sculpin were collected in the shallow sublittoral habitat only in the Strait of Juan de Fuca, in winter beach seine collections at Beckett Point. Shrimp, including hippolytids such as Heptacarpus tenuissimus, crangonids such as Sclerocrangon alata and Crangon sp., and unidentified pandalids, composed 83.5% of the total IRI. Gammarid amphipods and polychaete annelids were of minor importance (Fig. B-40).

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. WW BS, STATION ALL
PREDATOR 8831020401 - ARTEDIUS FENESTRALIS
(PADDED SCULPIN) ADJUSTED SAMPLE SIZE = 15



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	80.00	47.92	12.14	4804.8	88.70
SPHAEROMATIDAE	33.00	2.92	3.23	202.9	3.70
PLEOCYEMATA-CARIDEA	20.00	1.67	13.69	307.2	5.70
HARPACTICOIDA	13.00	3.33	.13	45.0	.80
TANAIDACEA	13.00	.83	.16	12.9	.20
POLYCHAETA	7.00	.42	.03	3.2	.10
EUCARIDA-DECAPODA-BRACHYRHYNCH	7.00	.42	.33	5.3	.10
BIVALVIA	7.00	.83	.26	7.6	.10
PROSOBRANCHIA	7.00	.42	.33	5.3	.10
ISOPODA	7.00	1.25	1.32	18.0	.30

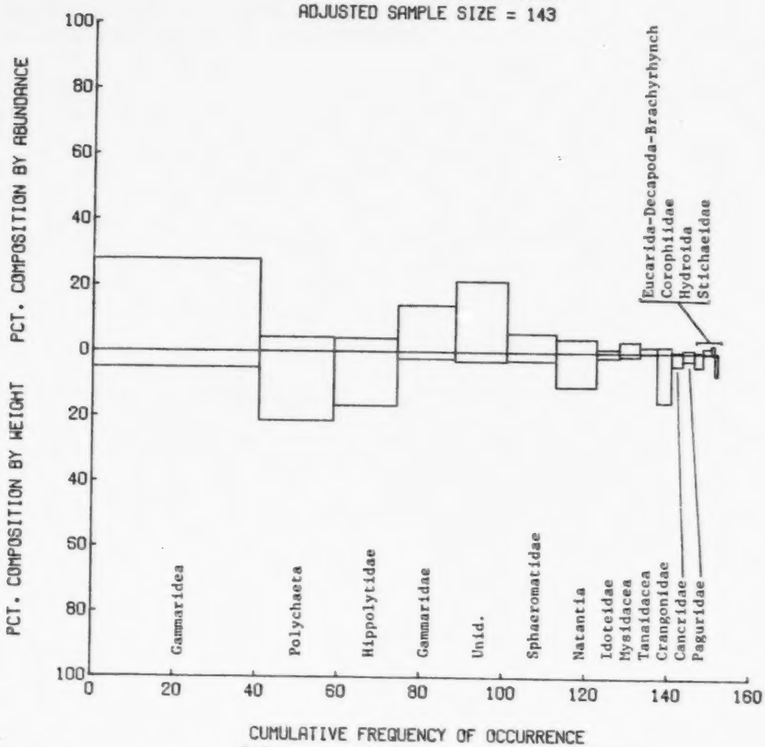
PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.23	.03	.79
SHANNON-WEINER DIVERSITY	1.21	1.11	.70
EVENNESS INDEX	.37	.33	.21

Fig. B-36. IRI prey spectrum of padded sculpin in shallow sublittoral habitats along eastern shoreline of northern Puget Sound.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA

8831020401 - ARTEDIUS FENESTRALIS
PADDED SCULPIN
ADJUSTED SAMPLE SIZE = 143



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	40.56	27.88	5.06	1335.8	43.73
POLYCHAETA	18.18	4.27	21.25	463.8	15.19
HIPPOLYTIDAE	15.38	3.97	16.53	315.4	10.33
GAMMARIDAE	13.99	14.09	2.23	228.2	7.47
UNIDENTIFIED	12.59	21.53	2.96	308.3	10.09
SPHAEROMATIDAE	11.89	5.75	2.67	100.2	3.28
NATANTIA	9.79	4.07	10.62	143.8	4.71
IDOTEIDAE	5.59	1.09	1.63	15.2	.50
MYSIDACEA	4.90	3.37	1.15	22.1	.72
TANAIDACEA	4.20	1.79	.12	8.0	.26
CRANGONIDAE	3.50	1.88	15.23	59.9	1.96
CANCRIDAE	2.90	.40	3.46	12.2	.40
PAGURIDAE	2.80	.99	2.35	9.4	.31
EUCARIDA-DECAPODA-BRACHYRHYNCH	2.10	.40	4.10	9.4	.31
COROPHIIDAE	2.10	1.59	.09	3.5	.12
HYDROIDA	.70	2.48	.21	1.9	.06
STICHAEIDAE	.70	.10	6.79	4.8	.16

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.16	.12	.24
SHANNON-WEINER DIVERSITY	3.37	3.51	2.64
EVENNESS INDEX	.66	.69	.51

Fig. B-37. IRI prey spectrum of padded sculpin in shallow sublittoral habitats along Strait of Juan de Fuca.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
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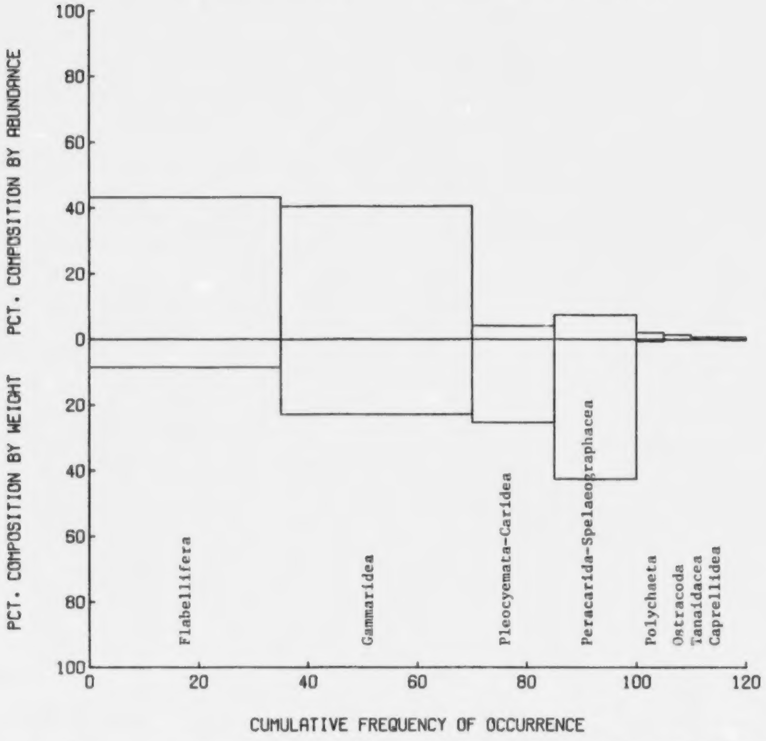
PREDATOR 8831020602 - BLEPSIAS CIRRHOSUS
(SILVERSPOTTED SCULP) ADJUSTED SAMPLE SIZE = 20



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                                  FREQ   NUM.   GRAV.   PREY    PERCENT
         PREY ITEM                OCCUR  COMP.  COMP.   I.R.I.  TOTAL IRI
----------------------------      -----  -----  -----   ------  ---------

 FLABELLIFERA                     35.00  43.24   8.44   1808.8    34.50
 GAMMARIDEA                       35.00  40.54  22.88   2219.7    42.30
 PLEOCYEMATA-CARIDEA              15.00   4.05  25.30    440.2     8.40
 PERACARIDA-SPELAEOGRAPHACEA      15.00   7.43  42.45    748.2    14.30
 POLYCHAETA                        5.00   2.03    .57     13.0      .20
 OSTRACODA                         5.00   1.35    .15      7.5      .10
 TANAIDACEA                        5.00    .68    .00      3.4      .10
 CAPRELLIDEA                       5.00    .68    .19      4.3      .10

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX              .36    .30                .33
      SHANNON-WEINER DIVERSITY            1.81   1.89               1.80
      EVENNESS INDEX                       .60    .67                .60
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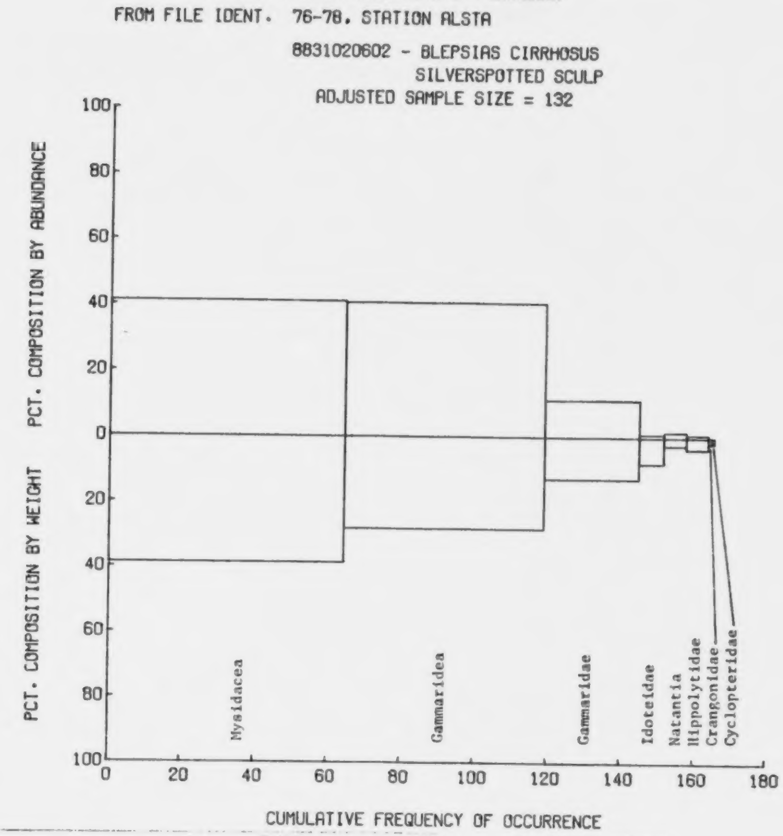
Fig. B-38. IRI prey spectrum in silver-spotted sculpins in shallow sublittoral waters of northern Puget Sound.



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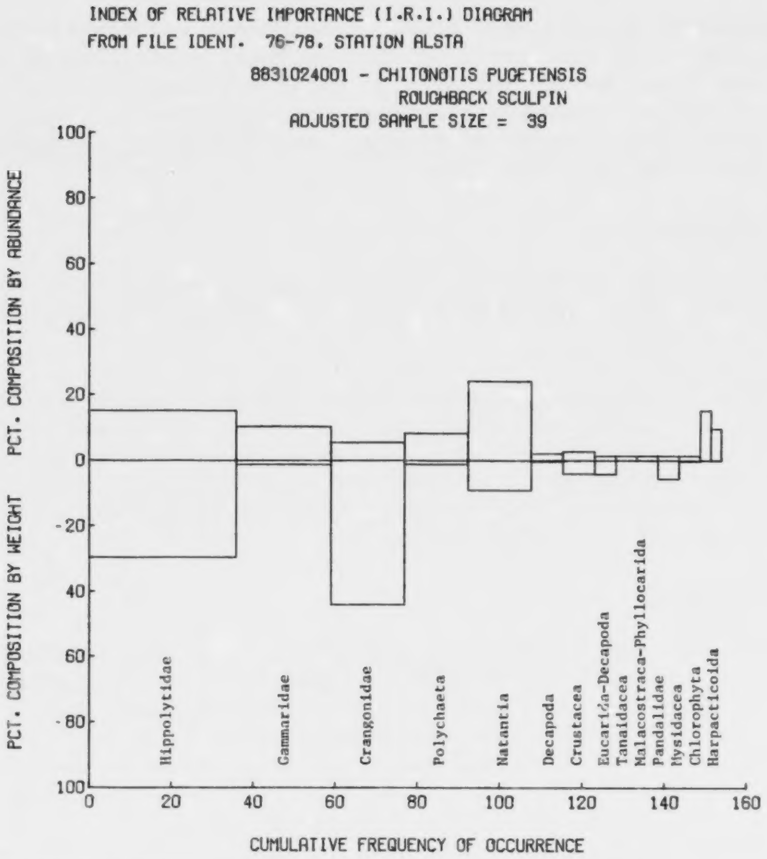
                                 FREQ   NUM.   GRAV.  PREY     PERCENT
          PREY ITEM              OCCUR  COMP.  COMP.  I.R.I.   TOTAL IRI
   ----------------------------  -----  -----  -----  ------   ---------

MYSIDACEA                        64.39  41.13  38.76  5144.3     53.32
GAMMARIDEA                       54.55  40.65  28.21  3756.4     38.93
GAMMARIDAE                       25.76  11.35  12.81   622.4      6.45
IDOTEIDAE                         6.82   1.00   8.02    61.5       .64
NATANTIA                          6.06   1.64   2.46    24.8       .26
HIPPOLYTIDAE                      6.06    .90   3.61    27.3       .28
CRANGONIDAE                        .76    .11   1.85     1.5       .02
CYCLOPTERIDAE                      .76    .05   1.85     1.4       .01

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

       PERCENT DOMINANCE INDEX             .35    .26                .44
       SHANNON-WEINER DIVERSITY           1.91   2.44               1.38
       EVENNESS INDEX                      .44    .56                .32
```

Fig. B-39. IRI prey spectrum of silverspotted sculpin in shallow sublittoral waters along Strait of Juan de Fuca.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
HIPPOLYTIDAE	35.90	15.07	29.50	1600.0	44.01
GAMMARIDAE	23.08	10.27	1.27	266.5	7.33
CRANGONIDAE	17.95	5.48	44.14	890.6	24.50
POLYCHAETA	15.38	8.22	1.23	145.4	4.00
NATANTIA	15.38	23.97	9.13	509.2	14.01
DECAPODA	7.69	2.05	.43	19.1	.53
CRUSTACEA	7.69	2.74	4.08	52.4	1.44
EUCARIDA-DECAPODA	5.13	1.37	4.19	28.5	.78
TANAIDACEA	5.13	1.37	.00	7.0	.19
MALACOSTRACA PHYLLOCARIDA	5.13	1.37	.05	7.3	.20
PANDALIDAE	5.13	1.37	5.62	35.9	.99
MYSIDACEA	5.13	1.37	.32	8.7	.24
CHLOROPHYTA	2.56	15.07	.00	38.6	1.06
HARPACTICOIDA	2.56	9.59	.00	24.6	.68

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.13	.30	.28
SHANNON-WEINER DIVERSITY	3.23	2.20	2.31
EVENNESS INDEX	.83	.56	.59

Fig. B-40. IRI prey spectrum of roughback sculpin in shallow sublittoral waters of the Strait of Juan de Fuca.

Sharpnose Sculpin

Sharpnose sculpin were found to be common members of the tidepool fish assemblages along the Strait of Juan de Fuca, especially at Slip Point, Morse Creek, and North Beach, but only at Point Williams were they collected by the beach seine. Gammarid amphipods and sphaeromatid isopods (Gnorimosphaeroma oregonensis, Exosphaeroma amplicauda, and Dynamenella sheareri) made up 94% of the total IRI (Fig. B-41).

Calico Sculpin

The stomachs of several calico sculpins collected at Fidalgo Island (Anacortes region) contained 23 gammarid amphipods and nine harpacticoid copepods.

Along the Strait of Juan de Fuca, however, calico sculpin appeared often in tidepool collections, mostly at Observatory Point and Slip Point. As with the sharpnose sculpin, gammarid amphipods and sphaeromatid isopods made up the majority of the IRI prey spectrum for the calico sculpin; however, barnacles (principally cirri) were also a numerous (40% of total prey abundance) component in the diet (Fig. B-42).

Mosshead Sculpin

Mosshead sculpins were not included in the collections in northern Puget Sound, due, perhaps, to the lack of sampling in rocky littoral habitats as they were often included in tidepool collections along the Strait of Juan de Fuca. They were particularly abundant at Slip Point and Observatory Point. The diet was more diverse and quite different from the other two Clinocottus species. Barnacles were the predominant prey organism while gammarid amphipods and sphaeromatid isopods did not contribute significantly to the diet (Fig. B-43). Algae (including Urospora mirabilis, Porphyra sp., and Iridaea sp.) composed 38.7% of the total IRI, followed by harpacticoid copepods, sabellid annelids, nemertean worms, and ostracods.

Buffalo Sculpin

Buffalo sculpins caught in northern Puget Sound had in their stomachs numerous pieces of algae (ulvoid type), constituting 61.8 percent of the total IRI, accompanied by two amphipods (25.0 percent), and one partly digested fish (13.2 percent). The sample size was too small, however, to determine whether the consumption of algae is representative of the food habits. Buffalo sculpins originating from the Cherry Point region also indicated a high contribution by algae. Nonalgae prey taxa included gammarid amphipods (13.8 percent of total IRI), insects (11.2 percent), polychaetes (9.2 percent), crabs (5.3 percent), nudibranchs (4.7 percent), pychnogonids (4.1 percent), sticks and organic debris (2.5 percent), and flabelliferan isopods (2.4 percent; primarily Exosphaeroma amplicauda).

Among the beach seine collections along the Strait of Juan de Fuca, juvenile buffalo sculpins were most common at Twin Rivers and Beckett Point. Tidepool collections at Observatory Point and North Beach also provided a few specimens. Gammarid amphipods, algae (including Enteromorpha intestinalis, Ulva fenestrata, Porphyra sp., and Phyllosphadix sp.), and polychaete annelids were identified as the principal components of the overall prey

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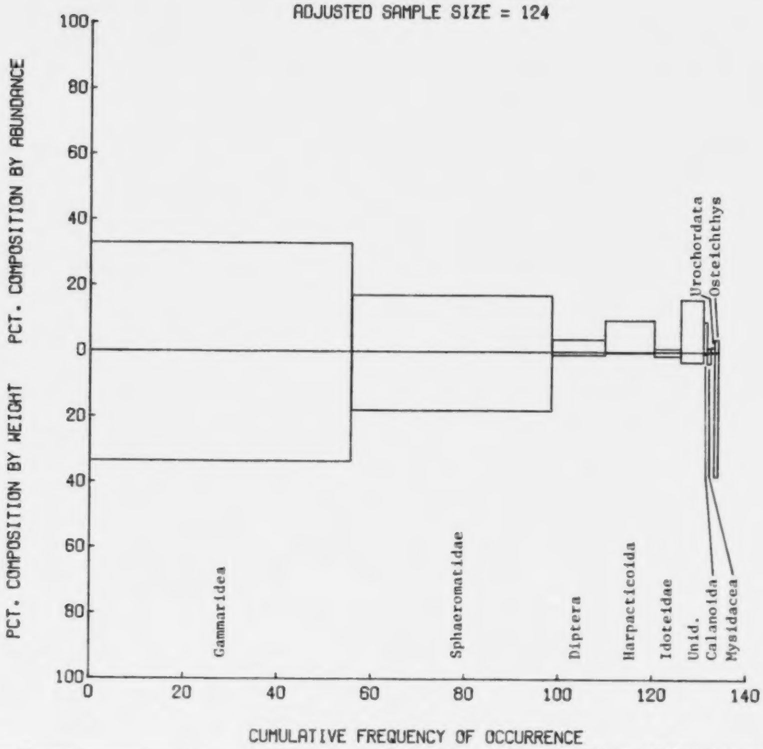
INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA

8831020701 - CLINOCOTTUS ACUTICEPS
SHARPNOSE SCULPIN
ADJUSTED SAMPLE SIZE = 124

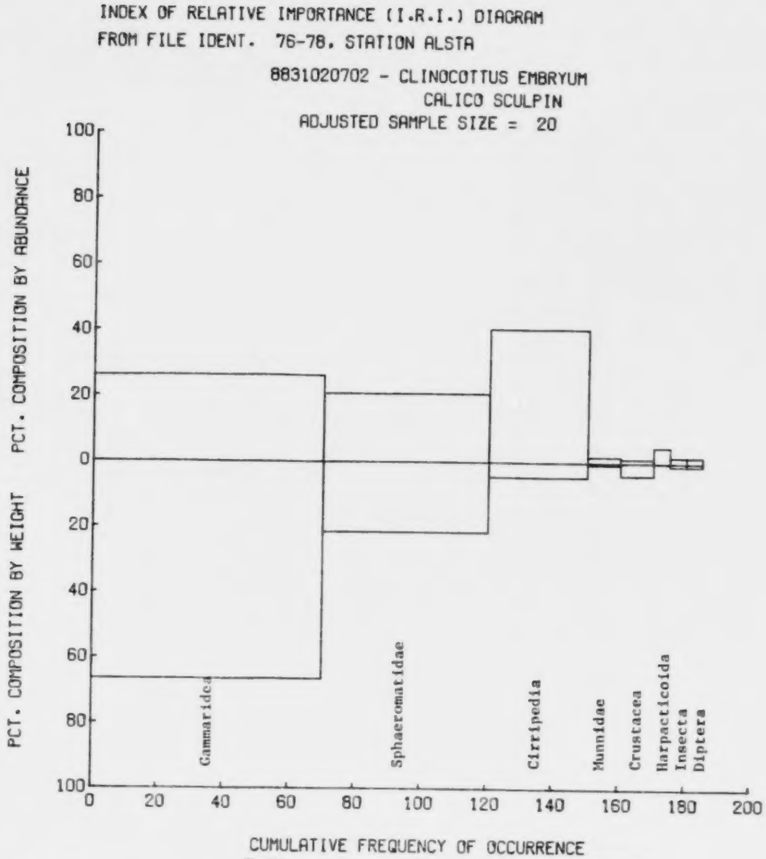


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	55.65	32.86	33.49	3692.4	67.08
SPHAEROMATIDAE	42.74	17.14	17.87	1496.2	27.18
DIPTERA	11.29	3.76	.94	53.0	.96
HARPACTICOIDA	10.48	9.62	.23	103.3	1.88
IDOTEIDAE	5.65	.94	1.35	12.9	.24
UNIDENTIFIED	4.84	15.96	3.11	92.3	1.68
CALANOIDA	.81	9.27	.56	7.9	.14
MYSIDACEA	.81	1.17	3.44	3.7	.07
UROCHORDATA	.81	1.53	.01	1.2	.02
OSTEICHTHYS	.81	3.87	37.86	33.7	.61

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.18	.29		.52
SHANNON-WEINER DIVERSITY	2.92	2.14		1.27
EVENNESS INDEX	.66	.49		.29

Fig. B-41. IRI prey spectrum of sharpnose sculpin in shallow sublittoral and littoral habitats along the Strait of Juan de Fuca.



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                                    FREQ   NUM.   GRAV.   PREY     PERCENT
        PREY ITEM                   OCCUR  COMP.  COMP.   I.R.I.   TOTAL IRI
--------------------------------    -----  -----  -----   ------   ---------

GAMMARIDEA                          70.00  26.19  66.52   6489.8     64.29
SPHAEROMATIDAE                      50.00  20.83  21.54   2118.7     20.99
CIRRIPEDIA                          30.00  40.48   4.53   1350.3     13.38
MUNNIDAE                            10.00   1.79    .54     23.2       .23
CRUSTACEA                           10.00   1.19   3.90     50.9       .50
HARPACTICOIDA                        5.00   4.76    .05     24.1       .24
INSECTA                              5.00   1.79    .97     13.8       .14
DIPTERA                              5.00   1.79    .97     13.8       .14

  PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
  COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
  (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX              .28    .49                  .48
      SHANNON-WEINER DIVERSITY            2.19   1.50                 1.39
      EVENNESS INDEX                       .66    .45                  .42
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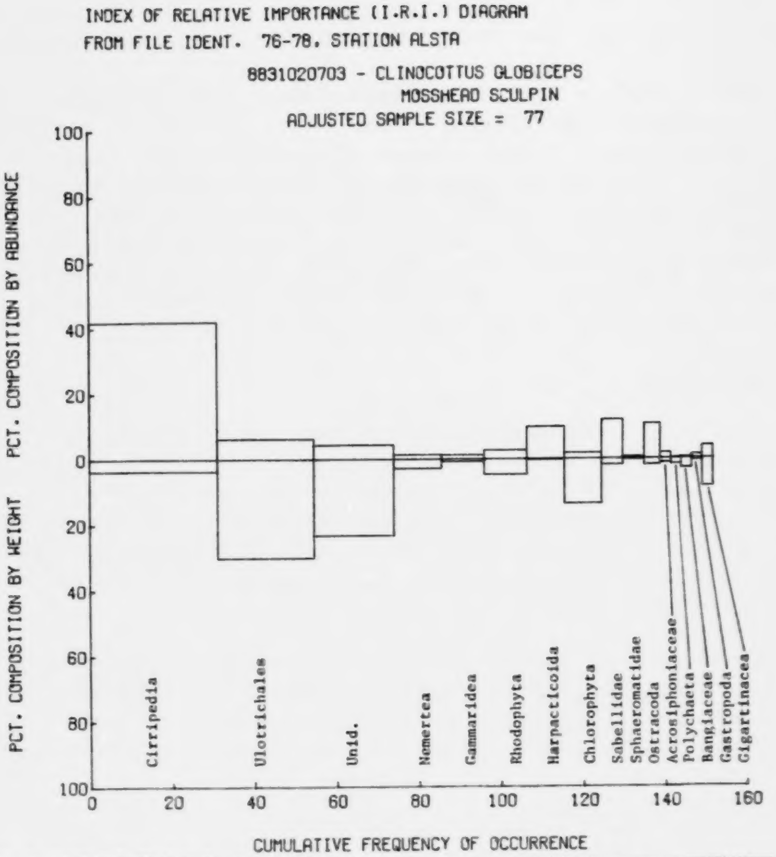
Fig. B-42. IRI prey spectrum of calico sculpin in littoral habitats along Strait of Juan de Fuca.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CIRRIPEDIA	31.17	41.89	3.68	1420.3	42.17
ULOTRICHALES	23.38	6.22	30.04	847.6	25.17
UNIDENTIFIED	19.48	4.32	23.22	536.7	15.93
NEMERTEA	11.69	1.35	2.85	49.1	1.46
GAMMARIDEA	10.39	1.22	.78	20.7	.62
RHODOPHYTA	10.39	2.70	4.75	77.4	2.30
HARPACTICOIDA	9.09	9.73	.26	90.8	2.70
CHLOROPHYTA	9.09	1.76	13.63	139.9	4.15
SABELLIDAE	5.19	11.76	1.95	71.2	2.11
SPHAEROMATIDAE	5.19	.54	.24	4.1	.12
OSTRACODA	3.90	10.54	1.95	48.7	1.45
ACROSIPHONIACEAE	2.60	1.76	1.35	8.1	.24
POLYCHAETA	2.60	.27	1.72	5.2	.15
BANGIACEAE	2.60	.27	3.00	8.5	.25
GASTROPODA	2.60	1.08	.68	4.6	.14
GIGARTINAC EA	2.60	3.78	8.54	32.0	.95

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.22	.18	.27
SHANNON-WEINER DIVERSITY	2.92	3.05	2.40
EVENNESS INDEX	.67	.69	.55

Fig. B-43. IRI prey spectrum of mosshead sculpin in littoral habitats along the Strait of Juan de Fuca.

spectrum (Fig. B-44). The high incidence (31.5% of total IRI) of algae again suggests that they may constitute more than an incidentally consumed food item.

Adult buffalo sculpin collected in a gravel-cobble habitat in Nisqually Reach, southern Puget Sound (Fresh et al. 1979), had consumed algae (also principally ulvoid types) almost exclusively, such that 93% of the total IRI was algae. Most of the prey animals were gammarid amphipods and polychaete annelids. Johnson's (1968) in-depth analysis of the food habits of buffalo sculpin in Humboldt Bay, California, indicated that caprellid (*Caprella* sp.) and gammarid amphipods (inc. *Amphithoe* sp.) were the predominant food organisms, composing 66.3% of the total IRI spectrum (Fig. B-45). Again, algae (*Ulva lobata*) were a major component (16.4% of total IRI) in the diet.

Red Irish Lord

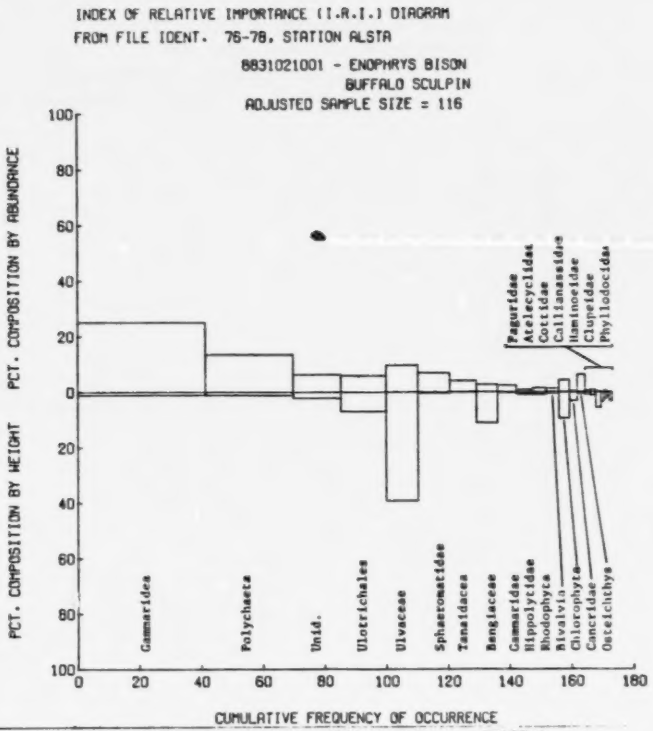
Red Irish lord were characteristic of the demersal fish assemblage in the gravel-cobble pocket beach habitats in northern Puget Sound and were often found in the rocky/kelp bed habitat. They appeared to be an almost completely bottom-oriented carnivore, preying on flabelliferan isopods (42.8 percent of total IRI), brachyuran crabs (39.9 percent; *Cancer magister*, *C. oregonensis*, *C. productus*, *Pugettia gracilis*, *Mimulus* sp.), fish (13.4 percent), and shrimp (1.3 percent).

Although they were not frequently collected along the Strait of Juan de Fuca during the MESA studies, Leaman (1976) identified them as common members of the *Nereocystis* kelp bed assemblage in Barkley Sound, outer Vancouver Island, his documentation of their prey organisms indicated approximately equal gravimetric contributions by crabs (*Pachycheles rudis*, *Loxorhynchus crispatus*, *Cancer oregonensis*), gammarid amphipods (*Erichtonius brasiliensis*) and caprellid amphipods (*Caprella equilibra*, *C. incisa*, *C. natalensis*, *C. laeviscula*, *C. mendax*, *C. ferrea*).

Longfin Sculpin

The longfin sculpin was the most frequently observed cottid and third most common species over the combined SCUBA transect observations (85 percent frequency of occurrence) in the rocky/kelp bed habitat of northern Puget Sound. The prey spectrum was very diverse, with a number of rare prey items included in the overall sample. Harpacticoid copepods were the most important prey, contributing 55.4 percent of the total IRI; polychaetes (23.9 percent), crabs (8.7 percent), gammarid amphipods (5.7 percent), shrimp (1.5 percent), and crab larvae, (1.5 percent) were of secondary importance. Although epibenthic organisms were taken more frequently, benthic organisms made the greatest contribution to the total prey biomass.

Longfin sculpins also appear to be common members of the rocky/kelp bed habitats along the Strait of Juan de Fuca (Jeff Cross, Univ. Wash., unpub. data) and in the *Nereocystis* kelp bed habitat along the outer coast of Vancouver Island (Leaman 1976). In the latter region, gammarid amphipods (*Parapleustes pugettensis*, *Photis californica*, *Erichtonius brasiliensis*) appeared to be their most important prey, supplemented by other caridean crustaceans and polychaete annelids.



INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA
8831021001 - ENOPHRYS BISON
BUFFALO SCULPIN
ADJUSTED SAMPLE SIZE = 116

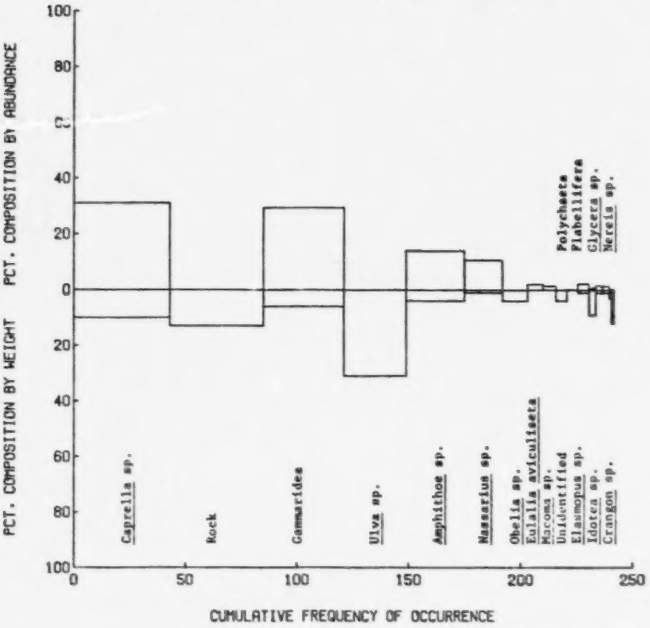
PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	41.38	25.06	1.13	1083.6	40.25
POLYCHAETA	29.45	13.49	1.22	418.5	15.54
UNIDENTIFIED	15.52	6.27	2.17	131.0	4.86
ULOTRICHALES	14.66	5.90	7.01	189.3	7.03
ULVACEAE	10.34	9.64	39.26	505.8	18.79
SPHAEROMATIDAE	10.34	6.87	.40	75.2	2.79
TANAIDACEA	8.62	3.98	.03	34.5	1.28
BANGIACEAE	6.90	2.65	11.16	95.3	3.54
GAMMARIDAE	6.03	2.41	.21	15.8	.59
HIPPOLYTIDAE	5.17	.84	.88	8.9	.33
RHODOPHYTA	4.31	1.45	.92	10.2	.38
BIVALVIA	4.31	1.20	.47	7.2	.27
CHLOROPHYTA	3.45	4.34	9.50	47.7	1.77
CANCRIDAE	2.59	.36	3.22	9.3	.34
OSTEICHTHYS	2.59	6.27	.67	17.9	.67
PAGURIDAE	1.72	.60	1.01	2.8	.10
ATELECYCLIDAE	1.72	.84	1.17	3.5	.13
COTTIDAE	1.72	.24	5.60	10.1	.37
CALLIANASSIDAE	.86	.12	3.33	3.0	.11
HAMINOEIDAE	.86	.60	2.33	2.5	.09
CLUPEIDAE	.86	.12	1.52	1.5	.06
PHYLLODOCIDAE	.86	.12	3.27	2.9	.11

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.11	.19	.23
SHANNON-WEINER DIVERSITY	3.85	3.36	2.73
EVENNESS INDEX	.71	.62	.50

Fig. B-44. IRI prey spectrum of buffalo sculpin in shallow sublittoral habitats along Strait of Juan de Fuca.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. JOHNSN. STATION 1968
PREDATOR 8831021001 - ENOPHRYS BISON
(BUFFALO SCULPIN) ADJUSTED SAMPLE SIZE = 88



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CAPRELLA SP.	43.00	31.10	10.00	1767.3	33.40
ROCK	42.00	.00	13.00	546.0	10.30
GAMMARIDEA	36.00	29.40	6.00	1274.4	24.10
ULVA SP.	28.00	-.00	31.00	868.0	16.40
AMPHITHOE SP.	26.00	14.00	4.00	468.0	8.80
NASSARIUS SP.	17.00	10.70	1.00	198.9	3.80
OBELIA SP.	11.00	.00	4.00	44.0	.80
EULALIA AVICULISETA	7.00	2.00	.00	14.0	.30
MACOMA SP.	6.00	1.40	.00	8.4	.20
UNIDENTIFIED	5.00	.00	4.00	20.0	.40
ELASMOPUS SP.	5.00	.20	.00	1.0	.00
IDOTEA SP.	5.00	2.30	1.00	16.5	.30
CRANGON SP.	3.00	.70	9.00	29.1	.50
POLYCHAETA	3.00	1.60	1.00	7.8	.10
FLABELLIFERA	3.00	1.40	1.00	7.2	.10
GLYCERA SP.	1.00	.20	3.00	3.2	.00
NEREIS SP.	1.00	.20	12.00	12.2	.20

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.22	.16	.22
SHANNON-WEINER DIVERSITY	2.40	3.14	2.51
EVENNESS INDEX	.65	.82	.64

Fig. B-45. IRI prey spectrum of buffalo sculpin generated from data included in Johnson's (1968) analysis of their food habits in Humboldt Bay, California.

Pacific Staghorn Sculpin

Staghorn sculpins were probably the most ubiquitous cottid in the shallow sublittoral region of northern Puget Sound. Considering the sample size from this region, the overall prey spectrum (Fig. B-46) is not very diverse. Emphasis is on benthic organisms, with flabelliferan isopods (32.2 percent of total IRI), and bivalve siphons (29.6 percent) being equally important; polychaetes follow with 11.5 percent. Crabs account for 8.9 percent of the total IRI; fish, 51.7 percent; crab larvae, 4.3 percent; tanaids, 3.3 percent; gammarid amphipods (including *Atylus* sp., *Allorchestes* sp., *Paraphoxus spinosa*, and *Euhaustorius* sp., *Paraphoxus spinosa*, and *Euhaustorius* sp.), 1.3 percent; and bivalves, 0.5 percent. Although not as frequently preyed upon, fish (including juveniles and larvae of Pacific herring and juvenile striped seaperch, *Embiotoca lateralis*) and oxyrhynchan crabs actually composed the majority of the biomass ingested. Included in the decapod and general peracaridan crustacean categories were *Crangon franciscorum*, *Idotea resecata*, and *Cancer magister*.

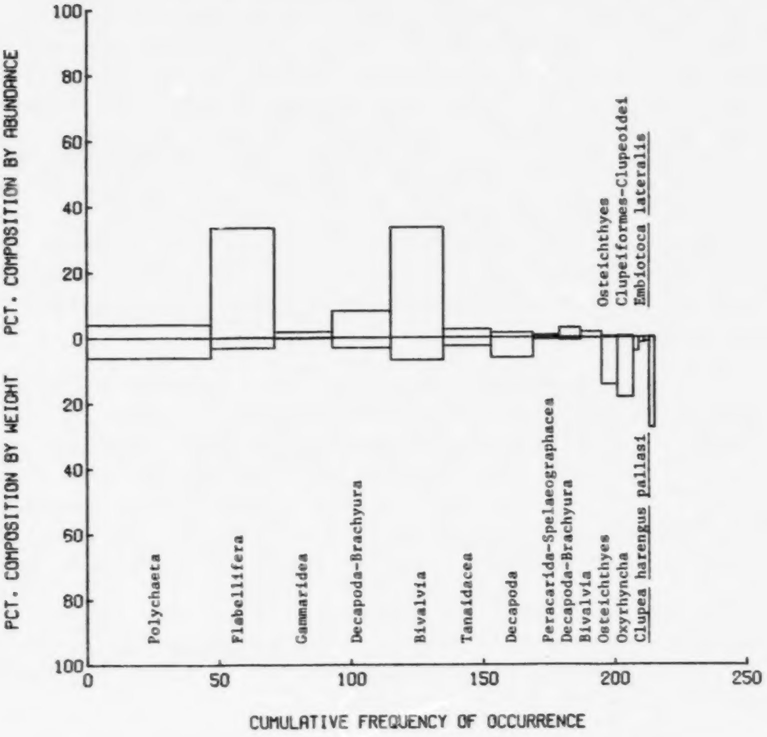
Also, the most common nearshore demersal species collected along the eastern shoreline, they occurred dominantly in collections at the Fidalgo Bay, Drayton Harbor, and Padilla Bay mud/eelgrass sites and the Brich Bay sand/ eelgrass site. Overall prey composition from the eastern sites is dramatically different than those in the western area (Fig. B-47). Gammarid amphipods are much more important, providing 69.8 percent of the total IRI. Other prey taxa are rather equally represented by crabs (8.8 percent, *Hemigrapsus oregonensis*, *H. nudus*, *Cancer magister*, *Pinnixa* sp., and Paguridae), shrimp (8.2 percent; Crangonidae, Callianassidae, including *Upogebia pugettensis*, and Penaeidae), isopods (5.7 percent, *Exosphaeroma amplicauda*, *E. media*), fish (3.2 percent; juvenile staghorn sculpins, shiner perch, and rockfishes), and polychaete annelids (3.2 percent).

Along the Strait of Juan de Fuca, Pacific staghorn sculpin were one of the few nearshore demersal species which occurred commonly in the beach seine collections at all sites; however, collections at Jamestown and Beckett Point provided more specimens than the other sites. The diverse prey spectrum (Fig. B-48) included both benthic and epibenthic organisms and, unlike the northern Puget Sound spectrum, was dominated by fish (46% of total IRI, including buffalo sculpin, *Enophrys bison*, shiner perch, *Cymatogaster aggregata*, Pacific sand lance, tube-snout, *Aulorhynchus flavidus*, juvenile salmon, *Oncorhynchus* sp., other Pacific staghorn sculpin, *Leptocottus armatus*, and unidentified flatfish, Pleuronectidae), true shrimp (17.5% of total IRI, including *Heptacarpus taylori*, *Pandalus danae*, *Crangon alaskensis*, and *C. stylirostris*), mysids (11.7% of total IRI, including *Neomysis awatschensis*), polychaete annelids, and crabs (6.2% of total IRI, including *Pugettia richi*, *Telmessus cheiragonus*, *Cancer magister*, and *Hemigrapsis oregonensis*).

Jones (1962) extensive studies of *Leptocottus* populations in Tomales Bay, California, included documentation of an overall diet oriented almost exclusively toward benthic shrimp (*Crangon* sp. and *Upogebia pugettensisa*, 92.3% of total IRI combined); fish (northern anchovy, *Engraulis mordax* and shore crabs (*Hemigrapsus oregonensis*) were secondary prey organisms (Fig. B-49). Life history studies of staghorn sculpins in Anaheim Bay (Tasto 1975) similarly illustrated both the variety of food organisms consumed and the importance of decapod crustaceans, specifically *Pinnixa* sp., *Hemigrapsus oregonensis* and

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD, STATION ALSTA

PREDATOR 8831021801 - LEPTOCOTTUS ARMATUS
(PAC. STAGHORN SCULPN) ADJUSTED SAMPLE SIZE = 51



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
POLYCHAETA	47.00	4.06	6.06	475.6	15.60
FLABELLIFERA	24.00	33.42	3.14	877.4	28.70
GAMMARIDEA	22.00	1.72	.18	41.8	1.40
DECAPODA-BRACHYURA	22.00	8.12	3.12	315.9	10.30
BIVALVIA	20.00	33.51	6.82	806.6	26.40
TANAIDACEA	18.00	2.50	2.53	90.5	3.00
DECAPODA	16.00	1.39	6.14	120.3	3.90
PERACARIDA-SPELAEOGRAPHACEA	10.00	.69	.53	12.2	.40
DECAPODA-BRACHYURA	8.00	2.85	.73	28.6	.90
BIVALVIA	8.00	1.64	.14	14.2	.50
OSTEICHTHYES	6.00	.35	14.31	88.0	2.90
OXYRHYNCHA	6.00	.43	18.22	111.9	3.70
CLUPEA HARENGUS PALLASI	2.00	.09	4.06	8.3	.30
OSTEICHTHYES	2.00	.09	1.50	3.2	.10
CLUPEIFORMES-CLUPEOIDEI	2.00	.09	1.22	2.6	.10
EMBIOTOCA LATERALIS	2.00	.17	27.54	55.4	1.80

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.23	.15	.19
SHANNON-WEINER DIVERSITY	2.26	3.04	2.81
EVENNESS INDEX	.56	.76	.70

Fig. B-46. IRI prey spectrum of staghorn sculpins in northern Puget Sound.

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INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. WW BS. STATION ALL
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       (PAC. STAGHORN SCULPN)   ADJUSTED SAMPLE SIZE = 91
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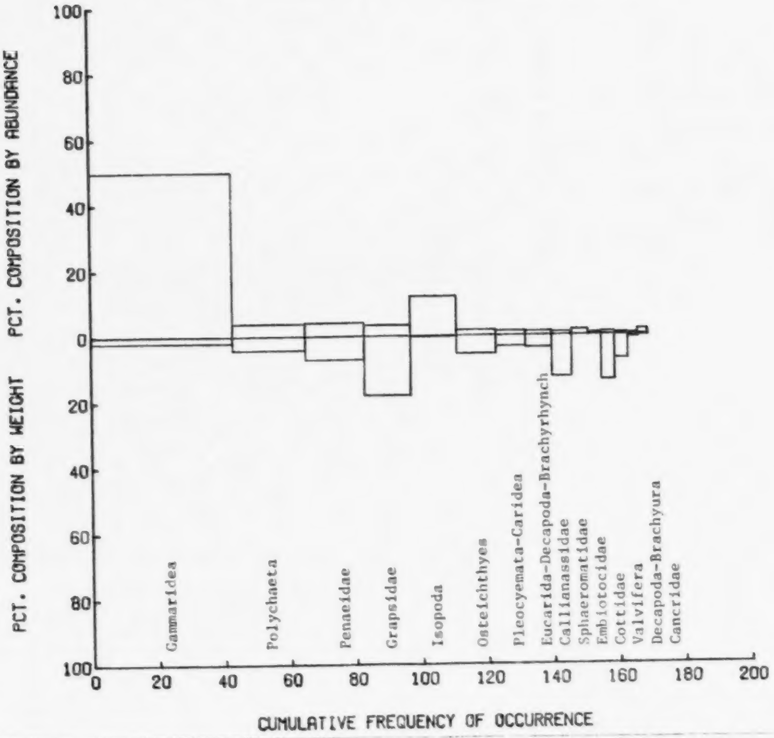

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                                    FREQ   NUM.   GRAV.  PREY    PERCENT
         PREY ITEM                  OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
 ----------------------------       -----  -----  -----  ------  ---------

GAMMARIDEA                          43.00  50.07   1.97  2237.7    64.50
POLYCHAETA                          22.00   3.86   4.24   178.2     5.10
PENAEIDAE                           18.00   4.13   7.10   202.1     5.80
GRAPSIDAE                           14.00   3.33  18.00   298.6     8.60
ISOPODA                             14.00  11.98    .28   175.8     5.10
OSTEICHTHYES                        12.00   1.70   5.57    87.2     2.50
PLEOCYEMATA-CARIDEA                  9.00   1.33   3.38    42.4     1.20
EUCARIDA-DECAPODA-BRACHYRHYNCH       8.00   1.20   3.78    39.8     1.10
CALLIANASSIDAE                       6.00    .93  12.72    54.6     1.60
SPHAEROMATIDAE                       5.00   1.60    .09     8.4      .20
EMBIOTOCIDAE                         4.00    .93  13.81    59.0     1.70
COTTIDAE                             4.00    .53   7.32    31.4      .90
VALVIFERA                            3.00   1.60    .30     5.7      .20
DECAPODA-BRACHYURA                   2.00   4.13   2.13    12.5      .40
CANCRIDAE                            1.00    .13  17.49    17.6      .50

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                .27    .12              .43
      SHANNON-WEINER DIVERSITY              2.22   3.26             2.03
      EVENNESS INDEX                         .57    .83              .52
```
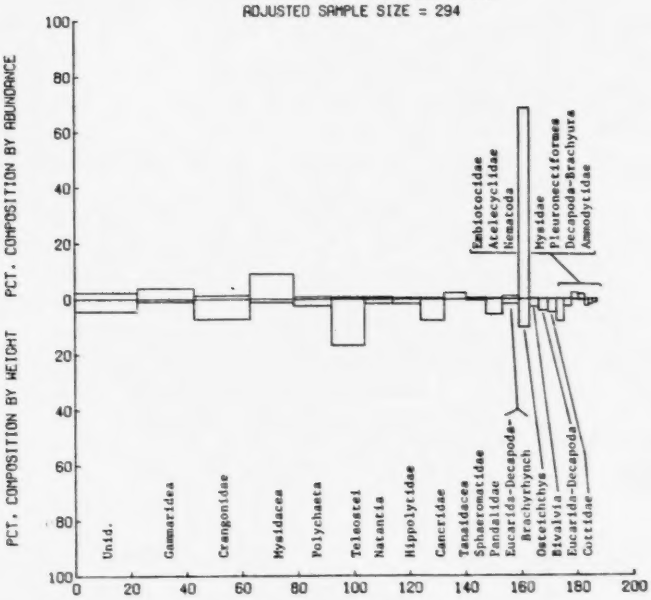

Fig. B-47. IRI prey spectrum of staghorn sculpins from shallow sublittoral habitats along eastern shoreline of northern Puget Sound.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78. STATION ALSTA

8831021801 - LEPTOCOTTUS ARMATUS
PAC. STAGHORN SCULPN
ADJUSTED SAMPLE SIZE = 294



CUMULATIVE FREQUENCY OF OCCURRENCE

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
UNIDENTIFIED	22.45	2.33	4.46	152.4	10.73
GAMMARIDEA	20.41	3.85	.93	97.6	6.87
CRANGONIDAE	20.07	1.24	7.22	169.7	11.95
MYSIDACEA	15.65	9.06	1.19	160.4	11.29
POLYCHAETA	13.61	.90	2.45	45.6	3.21
TELEOSTEI	11.90	.74	16.68	207.3	14.60
NATANTIA	10.20	.72	1.58	23.5	1.65
HIPPOLYTIDAE	9.86	.49	1.73	21.8	1.54
CANCRIDAE	8.50	.50	7.69	69.6	4.90
TANAIDACEA	7.82	2.30	.03	18.2	1.29
SPHAEROMATIDAE	7.14	.54	.38	6.6	.46
PANDALIDAE	5.78	.29	5.60	34.0	2.40
EUCARIDA-DECAPODA-BRACHYRHYNCH	5.78	.98	1.80	16.0	1.13
OSTEICHTHYS	3.74	68.44	10.23	294.4	20.73
BIVALVIA	3.40	.19	2.84	10.3	.72
EUCARIDA-DECAPODA	3.40	.12	4.29	15.0	1.06
COTTIDAE	3.06	.10	4.86	15.2	1.07
EMBIOTOCIDAE	2.72	.12	8.05	22.2	1.57
ATELECYCLIDAE	2.72	.08	2.71	7.6	.54
NEMATODA	2.38	2.21	.05	5.4	.38
MYSIDAE	2.38	1.76	.48	5.3	.37
PLEURONECTIFORMES	1.36	.04	2.63	3.6	.26
DECAPODA-BRACHYURA	1.36	.16	1.84	2.7	.19
AMMODYTIDAE	1.36	.05	1.30	1.8	.13
CLUPEIDAE	.34	.01	1.12	.4	.03

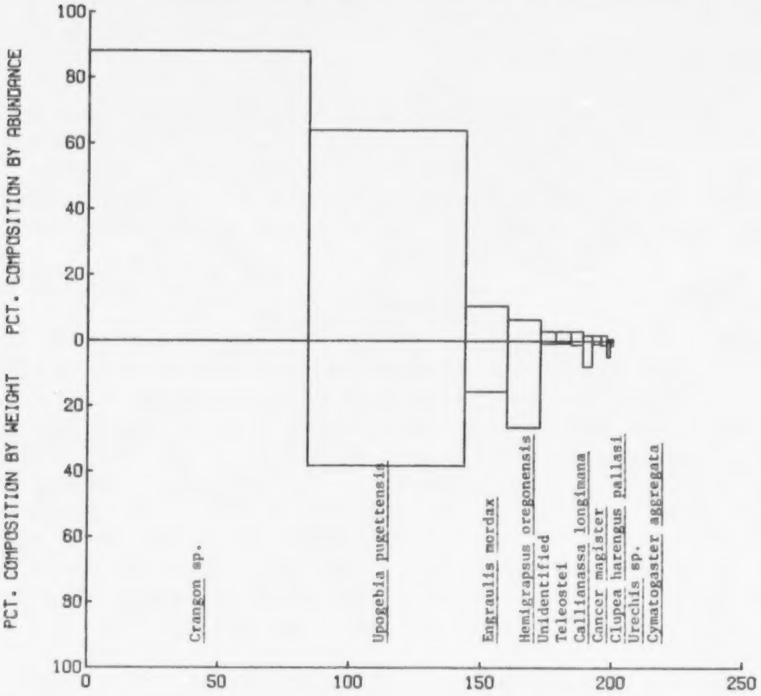
PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.48	.07		.11
SHANNON-WEINER DIVERSITY	2.14	4.40		3.63

Fig. B-48. IRI prey spectrum of staghorn sculpin in shallow sublittoral habitat of Strait of Juan de Fuca.

Reproduced from best available copy.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. JONES, STATION 1962
PREDATOR 8831021801 - LEPTOCOTTUS ARMATUS
(PAC. STAGHORN SCULPN) ADJUSTED SAMPLE SIZE = 87



CUMULATIVE FREQUENCY OF OCCURRENCE

```
                                 FREQ   NUM.   GRAV.  PREY     PERCENT
          PREY ITEM              OCCUR  COMP.  COMP.  I.R.I.   TOTAL IRI
  ---------------------------    -----  -----  -----  ------   ---------


 CRANGON SP.                     59.77  64.12  38.15  6112.7    86.40
 UPOGEBIA PUGETTENSIS            16.09  10.59  15.49   419.6     5.90
 ENGRAULIS MORDAX                12.64   6.47  26.43   415.9     5.90
 HEMIGRAPSUS OREGONENSIS          5.75   2.94    .70    20.9      .30
 UNIDENTIFIED                     5.75   2.94    .61    20.4      .30
 TELEOSTEI                        4.60   2.94   1.13    16.7      .30
 CALLIANASSA LONGIMANA            3.45   1.76   7.79    33.0      .50
 CANCER MAGISTER                  3.45   1.76    .84     9.0      .10
 CLUPEA HARENGUS PALLASI          2.30   1.76   1.19     6.9      .10
 URECHIS SP.                      1.15    .59   4.84     6.2      .10
 CYMATOGASTER AGGREGATTA          1.15    .59   1.43     2.3      .00

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX           1.21    .25                .75
      SHANNON-WEINER DIVERSITY          2.01   2.34                .81
      EVENNESS INDEX                     .56    .68                .24
```

Fig. B-49. IRI prey spectrum of Pacific staghorn sculpin in Tomales Bay, California documented by Jones (1962).

Callianassa sp. (Table B-5). Fish, mostly the arrow goby, Clevelandia ios, also occurred frequently.

Leptocottus from Everett Bay, central Puget Sound, examined by Conley (1977) had consumed mostly Corophium sp. and other gammarid amphipods, based on numbers, while other Leptocottus armatus and mud shrimp, Callianassa sp., composed the majority of the total prey biomass (Table B-6).

Great Sculpin

Great sculpins were retained only in collections from northern Puget Sound. One juvenile great sculpin from a beach seine collection at Deadman Bay had two unidentifiable decapods in its stomach. Another from a beach seine collection at Guemes Island contained 17 gammarid amphipods, 17 benthic gastropods (Littorina scutulata) and a piece of alga.

Tidepool Sculpin

Tidepool sculpin were numerically the predominant fish in the intertidal collections along the Strait of Juan de Fuca. They were especially abundant at four sites--Slip Point, Observatory Point, Twin Rivers, and North Beach. Gammarid amphipods and sphaeromatid isopod species (Gnorimosphaeroma oregonensis and Exosphaeroma amplicauda) dominated the prey spectrum (Fig. B-50), combining for 80.3% of the total IRI. Harpacticoid copepods (8.2% of total IRI), polychaete annelids (4.9%), and barnacles (4.3%) constituted the more important secondary prey items. Sphaeromatid isopods were quite important at the sites in the eastern half of the Strait but were only fourth or fifth in importance at the three western sites; there barnacles and harpacticoid copepods or hermit crabs replaced sphaeromatid isopods.

Nakamura's (1971) analysis of the food habits of tidepool sculpin at Port Renfrew, on the west coast of Vancouver Island, B.C., showed harpacticoid copepods and gammarid amphipods to numerically predominate; insects, polychaete annelids and isopods were of secondary importance (Table B-7).

Saddleback Sculpin

The saddleback sculpin was reported only from tidepool collections at Slip Point and Observatory Point in the Strait of Juan de Fuca. They had fed primarily upon gammarid amphipods (Fig. B-51); the second most important prey for the saddleback sculpin was harpacticoid copepods.

Fluffy Sculpin

Fluffy sculpins were common in collections from Slip Point, Observatory Point, and Neah Bay along the Strait of Juan de Fuca. Among the three Oligocottus species, gammarid amphipods contributed more to the prey spectrum of the fluffy sculpin; accordingly, sphaeromatid isopods were the least important in the diet of this species (Fig. B-52). The three isopod species--Gnorimosphaeroma oregonensis, Exosphaeroma amplicauda, and Dynamenella sheareri--were equally represented. Harpacticoid copepods, polychaetes, and idoteid isopods were secondary food organisms.

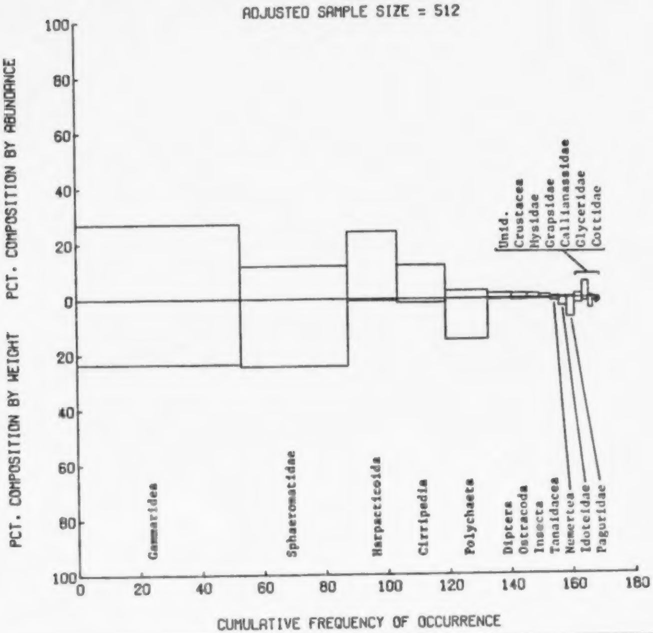
Table B-5. Prey composition (frequency of occurence) of Pacific staghorn sculpin in Anaheim Bay, California documented by Tasto (1975).

```
PREDATOR  8831021801 - LEPTOCOTTUS ARMATUS                      (PAC. STAGHORN SCULPN)


              INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                FROM FILE IDENT. REF 67. STATION SLSTA
              ******************************************

                                    FREQ    NUM.   GRAV.   PREY     PERCENT
         PREY ITEM                  OCCUR   COMP.  COMP.   I.R.I.   TOTAL IRI
  ---------------------------       -----   -----  -----   ------   ---------

   PINNIXA                          21.60
   HEMIGRAPSUS OREGONENSIS          20.70
   CALLIANASSA SP.                  17.40
   CLEVELANDIA IOS                  10.30
   DECAPODA                          8.90
   COROPHIUM ACHERUSICUM             6.10
   TELEOSTEI                         2.80
   AMPHITHOE SP.                     2.40
   FUNDULUS SP.                      1.90
   HYALE PLUMULOSA                   1.40
   DECAPODA                          1.40
   DIPTERA                           1.40
   POLYCHAETA                         .90
   GAMMARIDEA                         .90
   OXYUROSTYLIS SMITHI                .90
   CRANGON SP.                        .90
   EULALIA SP.                        .90
   HYALE SP.                          .90
   TAGELUS SP.                        .90
   GONIADA SP.                        .90
   LEPTOCOTTUS ARMATUS                .50
   ALLORCHESTES SP.                   .50
   CANCER ANTENNARIUS                 .50
   POTAMIDIDAE                        .50
   ATHERINOPS AFFINIS                 .50
   HYALE RUBRA                        .50
   CAPRELLA EQUILIBRA                 .50
   BIVALVIA                           .50
   PLEURONECTIDAE                     .50
   CLAUSIDAE                          .50

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

        PERCENT DOMINANCE INDEX              .00    .00               .00
        SHANNON-WEINER DIVERSITY             .00    .00               .00
        EVENNESS INDEX                       .00    .00               .00
```

Table B-6. Prey composition (numerical and gravimetric composition) of Pacific staghorn sculpin in Everett Bay, Washington, documented by Conley (1977).

```
PREDATOR  8831021801 - LEPTOCOTTUS ARMATUS                  (PAC. STAGHORN SCULPN)


               INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                 FROM FILE IDENT. REF 63, STATION SLSTA
               ********************************************

                                   FREQ   NUM.   GRAV.  PREY      PERCENT
         PREY ITEM                 OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  -----------------------------    -----  -----  -----  ------  ---------

   MYA                                      .10    .10
   CUMACEA                                  .20    .80
   CRANGON SP.                              .40    .50
   PLATICHTHYS STELLATUS                    .10    .10
   MYSIDACEA                               3.20    .10
   LEPTOCOTTUS ARMATUS                      .30  45.00
   GAMMARIDEA                             14.40    .40
   TELEOSTEI                                .10    .60
   CALLIANASSA SP.                          .60  23.00
   ISOPODA                                  .70    .10
   COROPHIUM SP.                          79.30   2.90
   GASTEROSTEUS ACULEATUS                   .10   1.00
   DECAPODA-BRACHYURA                       .20   3.00
   AMMODYTES HEXAPTERUS                     .20    .80
   MYTILUS SP.                              .10    .10

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

        PERCENT DOMINANCE INDEX             .65    .26                .00
        SHANNON-WEINER DIVERSITY           1.08   1.65                .00
        EVENNESS INDEX                      .28    .42                .00
```

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78. STATION ALSTA
8831022401 - OLIGOCOTTUS MACULOSUS
TIDEPOOL SCULPIN
ADJUSTED SAMPLE SIZE = 512



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	52.93	27.07	23.46	2674.7	54.62
SPHAEROMATIDAE	34.77	11.96	24.17	1255.9	25.65
HARPACTICOIDA	16.02	24.30	.61	399.0	8.15
CIRRIPEDIA	15.63	12.16	1.38	211.6	4.32
POLYCHAETA	13.67	2.64	14.72	240.0	4.90
DIPTERA	7.81	1.77	.26	15.9	.32
OSTRACODA	5.08	1.68	.59	11.5	.24
INSECTA	3.91	1.52	.37	7.4	.15
TANAIDACEA	3.71	1.09	.30	5.2	.11
NEMERTEA	2.73	.54	1.08	4.4	.09
IDOTEIDAE	2.54	.36	3.00	8.5	.17
PAGURIDAE	2.54	.39	7.00	18.8	.38
UNIDENTIFIED	2.54	1.45	2.00	8.8	.18
CRUSTACEA	1.95	5.79	1.24	13.7	.28
MYSIDAE	1.37	.75	3.84	6.3	.13
GRAPSIDAE	.98	.20	1.35	1.5	.03
CALLIANASSIDAE	.39	.05	2.35	.9	.02
GLYCERIDAE	.39	.11	1.76	.7	.01
COTTIDAE	.39	.05	1.57	.6	.01

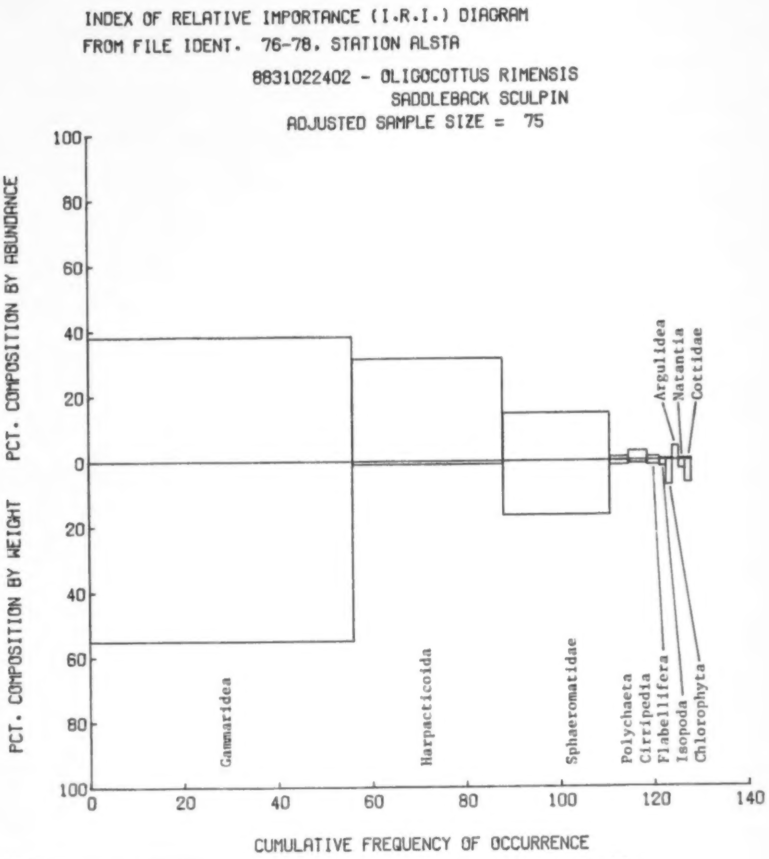
PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.17	.15	.38
SHANNON-WEINER DIVERSITY	3.27	3.63	1.90
EVENNESS INDEX	.55	.61	.32

Fig. B-50. IRI prey spectrum of tidepool sculpin in littoral habitats along the Strait of Juan de Fuca.

Table B-7. Prey composition (numerical composition) of tidepool sculpin at Port Renfrew, Vancouver Island, B.C., documented by Nakamura (1971).

```
PREDATOR  8831022401 - OLIGOCOTTUS MACULOSUS                   (TIDEPOOL SCULPIN     )


               INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                 FROM FILE IDENT. REF 68. STATION SLSTA
               ********************************************

                                    FREQ   NUM.   GRAV.  PREY     PERCENT
           PREY ITEM                OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
 ---------------------------        -----  -----  -----  ------  ---------

  OSTRACODA                                  .70
  COPEPODA                                 61.40
  MOLLUSCA                                   .40
  GAMMARIDEA                               23.60
  DECAPODA                                  1.00
  INSECTA                                   4.30
  OSTEICHTHYES                               .40
  ISOPODA                                   3.50
  ANNELIDA                                  4.30
  CAPRELLIDEA                                .10

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

     PERCENT DOMINANCE INDEX                 .44    .00             .00
     SHANNON-WEINER DIVERSITY               1.67    .00             .00
     EVENNESS INDEX                          .50    .00             .00
```

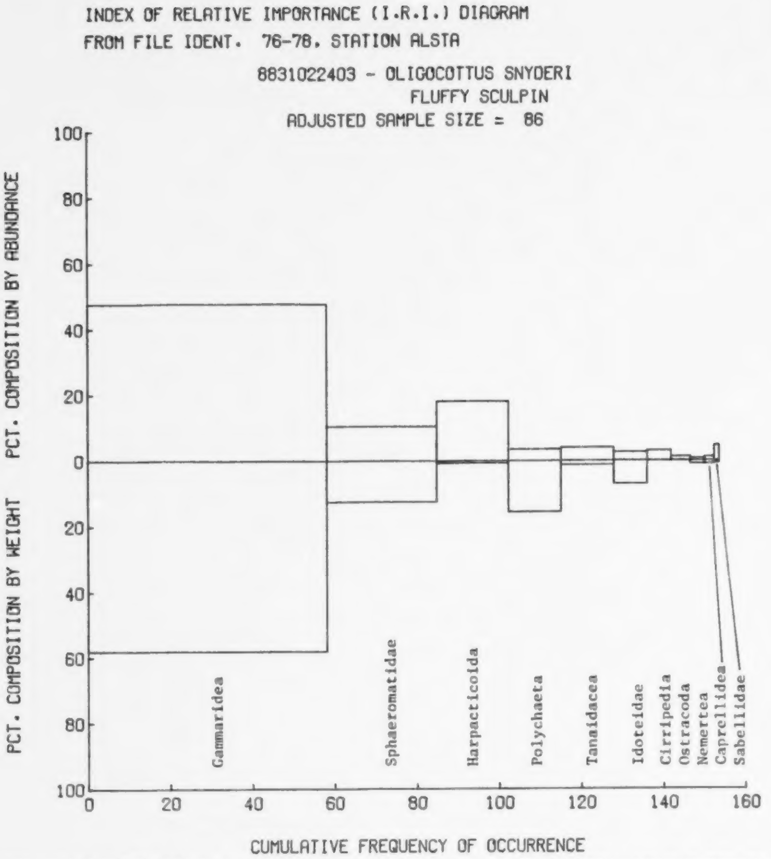


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	56.00	38.14	55.04	5218.5	74.16
HARPACTICOIDA	32.00	31.27	1.03	1033.7	14.69
SPHAEROMATIDAE	22.67	14.43	16.57	702.7	9.99
POLYCHAETA	4.00	1.03	1.44	9.9	.14
CIRRIPEDIA	4.00	2.75	.98	14.9	.21
FLABELLIFERA	2.67	1.03	1.44	6.6	.09
ISOPODA	1.33	.34	1.92	3.0	.04
CHLOROPHYTA	1.33	.34	7.68	10.7	.15
ARGULIDEA	1.33	4.12	.02	5.5	.08
NATANTIA	1.33	.34	2.64	4.0	.06
COTTIDAE	1.33	.34	6.96	9.7	.14

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.27	.34	.58
SHANNON-WEINER DIVERSITY	2.50	2.35	1.18
EVENNESS INDEX	.54	.51	.25

Fig. B-51. IRI prey spectrum of saddleback sculpin in littoral habitats along the Strait of Juan de Fuca.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	58.14	47.58	58.10	6143.7	81.64
SPHAEROMATIDAE	26.74	10.39	12.51	612.6	8.14
HARPACTICOIDA	17.44	18.01	.76	327.5	4.35
POLYCHAETA	12.79	3.46	15.64	244.3	3.25
TANAIDACEA	12.79	3.93	1.34	67.3	.89
IDOTEIDAE	8.14	2.54	7.14	78.8	1.05
CIRRIPEDIA	5.81	3.00	.14	18.3	.24
OSTRACODA	4.65	1.15	.03	5.5	.07
NEMERTEA	3.49	.69	1.00	5.9	.08
CAPRELLIDEA	2.33	1.15	1.00	5.0	.07
SABELLIDAE	1.16	4.62	.75	6.2	.08

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.28	.38	.68
SHANNON-WEINER DIVERSITY	2.61	1.99	1.09
EVENNESS INDEX	.60	.46	.25

Fig. B-52. IRI prey spectrum of fluffy sculpins from littoral habitats in Strait of Juan de Fuca.

In Nakamura's (1971) comparison of the food habits of *Oligocottus maculosus* and *O. snyderi* at Port Renfrew, Vancouver Island, B.C., *O. snyderi* was shown to feed much more upon gammarid amphipods than *O. maculosus*, while polychaete annelids and isopods were of secondary importance (Table B-8). Accordingly, harpacticoid copepods, which composed over 60% of the total number of prey consumed by *O. maculosus*, composed less than 5% of the prey consumed by *O. snyderi*.

Cabezon

Juvenile cabezon caught by beach seine at a cobble beach habitat (South Beach) in northern Puget Sound had full or nearly full stomachs. Oniscoidean isopods were the most important prey (55.6 percent of total IRI). Various epibenthic decapods (41.0 percent) including a shrimp (*Heptacarpus stimpsoni*), a crab (*Cancer oregonensis*), and amphipods (mostly *Eusiroides* sp., also *Atylus* sp. and *Allorchestes* sp.), and a parapagurid hermit crab (3.4 percent) were also included in the prey spectrum.

Cabezon from northeastern Guemes Island and Legoe Bay collections along the eastern shoreline had consumed Dungeness crab, *Cancer magister*, shrimp parts, and a rock.

O'Connel (1953) described the food habits of cabezon in California throughout their life history. Based on both frequency of occurrence and gravimetric composition, crustaceans (primarily shrimp, *Spirontocaris* sp. and Hippolytidae, crabs, *Cancer* sp., *Pugettia* sp. and Grapsidae, and gammarid amphipods) and fish (Cottidae, *Gibbonsia* sp. and Blennidae) were important prey of juveniles (Tables 9a and 10a); crustaceans (*Cancer* sp., *Pugettia* sp., *Scyra* sp., Grapsidae) and molluscs (Haliotis sp., Acmaeidae) were important in the diet of subadult (Tables 9b and 10b); and crustaceans (*Cancer* sp., Majidae, *Pugettia* sp., *Phyllolithodes* sp., *Scyra* sp., *Hemigrapsus* sp., *Pasurus* sp. *Cryptolithodes* sp., *Idotea* sp.), molluscs (*Haliotis* sp., Acmaeidae, Cephalopoda, *Mimulus* sp., Polyplacophora, Bivalvia) and fish (*Sebastes* sp., *Citharichthys* sp., Cottidae) were all important in the diets of adult cabezon (Tables 9c and 10c). O'Connel (1953) also illustrated seasonal differences where, based on gravimetric composition, crustaceans became more important than fish in the spring diet spectra for juvenile cabezon; molluscs were important to subadult cabezon just during spring; and fish and molluscs increased in proportional contribution during winter and spring in the diet of adult cabezon. In Quast's (1968) analysis of food habits of kelp bed fishes, decapod crustaceans and ceaphalopods (Theuthidida), predominated the diet of cabezon (based on frequency of occurrence) while fish (Perciformes), unidentified algae, other crustaceans and gastropods also occurred frequently (Table B-11).

Tubenose Poacher

Beach seine collections in the Strait of Juan de Fuca (Twin Rivers and Morse Creek) provided tubenose poacher stomach samples which illustrated a very specialized diet oriented almost exclusively toward mysids (Fig. B-53).

Table B-8. Prey composition (numerical composition) of fluffy sculpin at Port Renfrew, Vancouver Island, B.C., documented by Nakamura(1971).

```
PREDATOR  8831022403 - OLIGOCOTTUS SNYDERI                   (FLUFFY SCULPIN      )


              INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                FROM FILE IDENT. REF 68, STATION SLSTA
              *********************************************

                                  FREQ   NUM.   GRAV.  PREY     PERCENT
           PREY ITEM              OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   ----------------------------   -----  -----  -----  ------  ---------

  OSTRACODA                                .20
  COPEPODA                                3.60
  MOLLUSCA                                 .60
  GAMMARIDEA                             70.00
  DECAPODA                                 .60
  INSECTA                                  .60
  ISOPODA                                11.80
  ANNELIDA                               12.20
  CAPRELLIDEA                              .50

    PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
    COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
    (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

       PERCENT DOMINANCE INDEX             .52     .00              .00
       SHANNON-WEINER DIVERSITY           1.46     .00              .00
       EVENNESS INDEX                      .46     .00              .00
```

Table B-9. Prey composition (frequency of occurrence and gravimentric composition) for general prey categories consumed by juvenile (a), subadult (b), and adult (c) cabezon in central California documented by Connell(1953).

```
PREDATOR  883[illegible]3101 - SCORPAENICHTHYS MARMORATUS          (CABEZON


               INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                 FROM FILE IDENT. REF 69, STATION SLSTA
               *********************************************
```

a. juvenile

```
                                      FREQ   NUM.   GRAV.  PREY     PERCENT
          PREY ITEM                   OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  --------------------------          -----  -----  -----  ------  ---------

  CRUSTACEA                           75.00         46.40
  OSTEICHTHYES                        25.00         53.60

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

        PERCENT DOMINANCE INDEX              .00    .50                .00
        SHANNON-WEINER DIVERSITY             .00   1.00                .00
        EVENNESS INDEX                       .00   1.00                .00
```

b. subadult

```
                                      FREQ   NUM.   GRAV.  PREY     PERCENT
          PREY ITEM                   OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  --------------------------          -----  -----  -----  ------  ---------

  CRUSTACEA                           72.70         91.60
  MOLLUSCA                            18.20          5.10
  ROCK                                               3.30

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

        PERCENT DOMINANCE INDEX              .00    .84                .00
        SHANNON-WEINER DIVERSITY             .00    .50                .00
        EVENNESS INDEX                       .00    .31                .00
```

c. adult

```
                                      FREQ   NUM.   GRAV.  PREY     PERCENT
          PREY ITEM                   OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  --------------------------          -----  -----  -----  ------  ---------

  CRUSTACEA                           59.80         51.80
  MOLLUSCA                            27.40         16.70
  OSTEICHTHYES                         8.50         26.20
  UNIDENTIFIED                         3.40          3.40
  ANNELIDA                              .90          1.00
  ROCK                                               1.50

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

        PERCENT DOMINANCE INDEX              .00    .37                .00
        SHANNON-WEINER DIVERSITY             .00   1.75                .00
        EVENNESS INDEX                       .00    .68                .00
```

Table B-10. Prey composition (frequency of occurrence) for specific prey categories consumed by juvenile (a), subadult (b), and adult (c) cabezon in central California documented by Connell(1953).

```
PREDATOR  8831023101 - SCORPAENICHTHYS MARMORATUS          (CABEZON             )


              INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
               FROM FILE IDENT. REF 69, STATION SLSTA
              ********************************************
  a. juvenile
                                        FREQ   NUM.   GRAV.  PREY     PERCENT
           PREY ITEM                    OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   --------------------------           -----  -----  -----  ------  ---------

  SPIRONTOCARIS SP.                     42.86
  CANCER SP.                            17.14
  OSTEICHTHYES                          14.29
  GAMMARIDEA                            14.29
  COTTIDAE                               5.71
  GIBBONSIA SP.                          5.71
  PUGETTIA SP.                           2.86
  BLENNIDAE                              2.86
  GRAPSIDAE                              2.86
  HIPPOLYTIDAE                           2.86
  COPEPODA                               2.86

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                  .00    .00               .00
      SHANNON-WEINER DIVERSITY                 .00    .00               .00
      EVENNESS INDEX                           .00    .00               .00

  b. subadult
                                        FREQ   NUM.   GRAV.  PREY     PERCENT
           PREY ITEM                    OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   --------------------------           -----  -----  -----  ------  ---------

  CANCER SP.                            18.18
  PUGETTIA SP.                          18.18
  OSTEICHTHYES                           9.09
  SCYRA SP.                              9.09
  HALIOTIS SP.                           9.09
  GRAPSIDAE                              9.09
  ACMAEIDAE                              9.09

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                  .00    .00               .00
      SHANNON-WEINER DIVERSITY                 .00    .00               .00
      EVENNESS INDEX                           .00    .00               .00
```

Table B-10 (continued).

c. adult

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CANCER SP.	45.65				
MAJIDAE	45.65				
PUGETTIA SP.	43.48				
HALIOTIS SP.	16.30				
ACMAEIDAE	16.30				
PHYLLOLITHODES SP.	9.78				
SCYRA SP.	8.70				
SEBASTES SP.	5.43				
CEPHALOPODA	5.43				
UNIDENTIFIED	4.35				
MIMULUS SP.	4.35				
OSTEICHTHYES	4.35				
POLYPLACOPHORA	4.35				
BIVALVIA	2.17				
PAGURUS SP.	1.09				
CITHARICHTHYS SP.	1.09				
HEMIGRAPSUS SP.	1.09				
COTTIDAE	1.09				
CRYTOLITHODES SP.	1.09				
IDOTEA SP.	1.09				

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.00	.00	.00
SHANNON-WEINER DIVERSITY	.00	.00	.00
EVENNESS INDEX	.00	.00	.00

Table B-11. Prey composition (frequency of occurrence) of cabezon from southern California kelp beds documented by Quast(1968).

```
PREDATOR  8831023101 - SCORPAENICHTHYS MARMORATUS           (CABEZON               )


              INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                FROM FILE IDENT. REF 59. STATION SLSTA
              **********************************************

                                       FREQ   NUM.   GRAV.  PREY     PERCENT
           PREY ITEM                   OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  ---------------------------          -----  -----  -----  ------  ---------

 DECAPODA-PLEOCYEMATA                  69.00
 THEUTHIDIDA                           69.00
 PERCIFORMES                           25.00
 UNIDENTIFIED ALGAE                    25.00
 CRUSTACEA                             25.00
 PLEOCYEMATA-CARIDEA                   20.00
 GASTROPODA                            12.00
 BIVALVIA                               7.00
 CLUPEOMORPHA CLUPEIFORMES              7.00

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                   .00    .00                .00
      SHANNON-WEINER DIVERSITY                  .00    .00                .00
      EVENNESS INDEX                            .00    .00                .00
```

```
INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT.  76-78, STATION ALSTA
                          8831081101 - PALLASINA BARBATA
                                         TUBENOSE POACHER
                           ADJUSTED SAMPLE SIZE =  35
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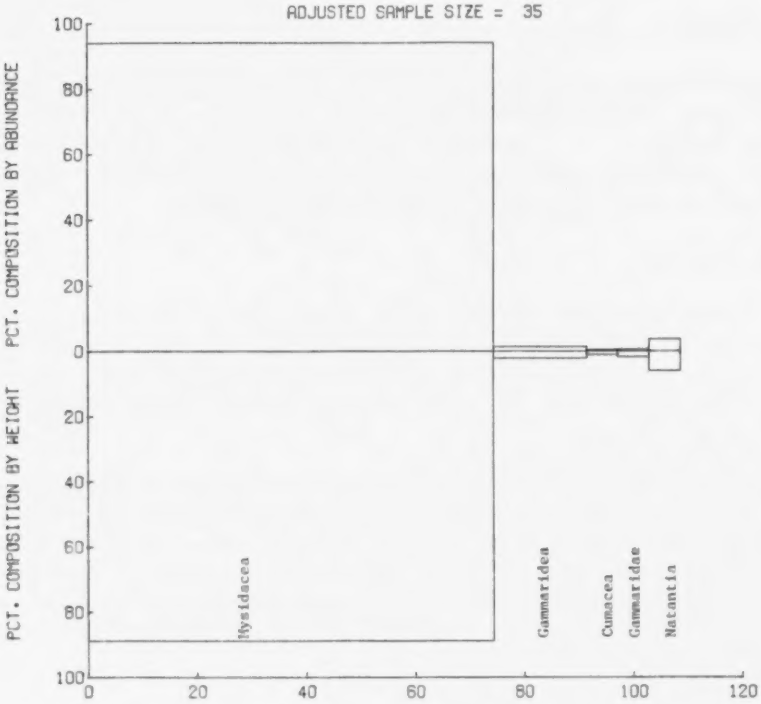


```
                                 CUMULATIVE FREQUENCY OF OCCURRENCE
                                 FREQ   NUM.   GRAV.  PREY     PERCENT
          PREY ITEM              OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  ----------------------------   -----  -----  -----  ------  ---------

MYSIDACEA                        74.29  94.07  88.80 13584.6    98.99
GAMMARIDEA                       17.14   1.34   2.21    60.9      .44
CUMACEA                           5.71    .38   1.12     8.6      .06
GAMMARIDAE                        5.71    .57   1.83    13.7      .10
NATANTIA                          5.71   3.63   6.04    55.3      .40

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX              .89    .79                  .99
      SHANNON-WEINER DIVERSITY             .41    .70                  .10
      EVENNESS INDEX                       .18    .30                  .04
```

Fig. B-53. IRI prey spectra of tubenose poacher from shallow sublittoral habitats in Strait of Juan de Fuca.

Tadpole Sculpin

Although they appeared in neritic (townet) collections from both northern Puget Sound and the Strait of Juan de Fuca, stomach contents originated only from collections in the Strait of Juan de Fuca. Gammarid amphipods and mysids were the prominent food organisms (Fig. B-54) suggesting an epibenthic feeding behavior.

Pacific Spiny Lumpsucker

Beach seine collections at Cherry Point and Legoe Bay provided the few Pacific spiny lumpsucker specimens for analysis of stomach contents. Gammarid amphipods supplied 56.1 percent of the total IRI, hyperiid amphipods, 36.8 percent. Caprellid amphipods (3.0 percent), valviferan isopods (3.1 percent), and cumaceans (0.6 percent) were incidental prey.

Sturgeon Poacher

Sturgeon poachers in the north Puget Sound collections originated from collections at Birch Bay. The total IRI was rather evenly distributed among cumaceans, gammarid amphipods, shrimp (Crangonidae and Penaeidae), and harpacticoid copepods. Polychaetes and tanaids were also found in the stomachs.

Along the Strait of Juan de Fuca, winter beach seine collections at Beckett Point and West Beach furnished the greatest number of sturgeon poachers for stomach analysis. The overall prey spectrum (Fig. B-55) was divided among cumaceans (36.3 of total IRI), gammarid amphipods (29.6%), and harpacticoid copepods (22.9%) as primary prey organisms, and crangonid shrimp (including *Crangon alaskensis* and *C. stylirostris*) as secondary prey.

Ribbon Snailfish

Beach seine and tidepool collections at Jamestown and Twin Rivers along the Straits of Juan de Fuca produced stomach samples of ribbon snailfish, wherein over 94% of the total IRI was contributed by gammarid amphipods. Sphaeromatid isopods (*Gnorimosphaeroma oregonensis* and *Exosphaeroma amplicauda*) and mysids provided the remaining 6% (Fig. B-56).

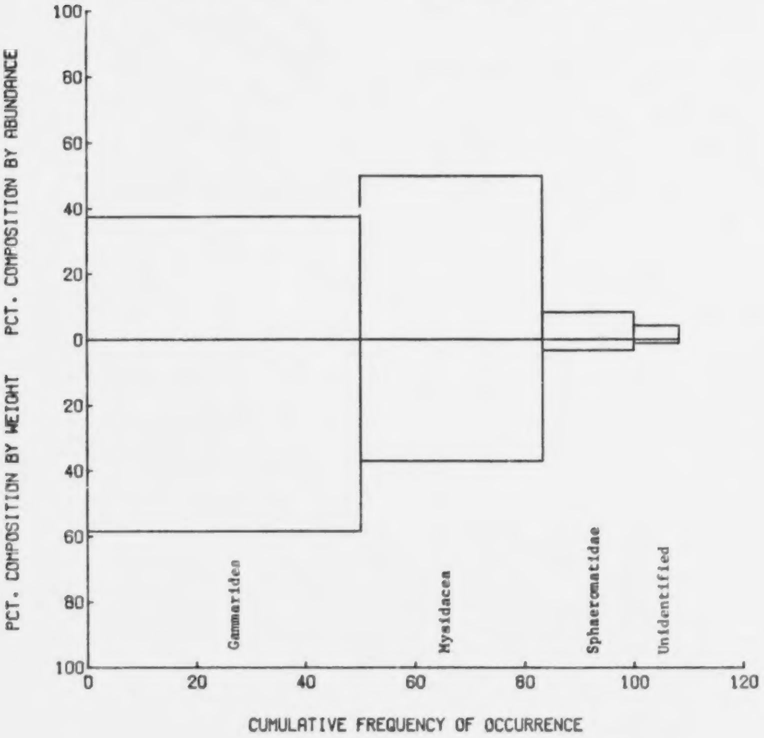
Tidepool Snailfish

Some tidepool snailfish from a beach seine collection at Birch Bay had consumed principally gammarid amphipods (41.4 percent of total IRI), polychaetes (39.8 percent) and valviferan isopods (15.4 percent), with shrimp (Penaeidae) providing a small contribution (3.4 percent).

Along the Strait, tidepool snailfish were the most common snailfish in the intertidal collections, and were regularly collected at Morse Creek, Observatory Point, and Slip Point. As in the case of the ribbon snailfish, gammarid amphipods contributed over 94% of the total IRI. Idoteid isopods (including *Synidotea* sp., *Idotea wosnesenski*, and *Pentidotea montereyensis*) and harpacticoid copepods were also common prey items (Fig. B-57).

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA

PREDATOR 8831070101 - PSYCHROLUTES PARADOXUS
(TADPOLE SCULPIN) ADJUSTED SAMPLE SIZE = 12

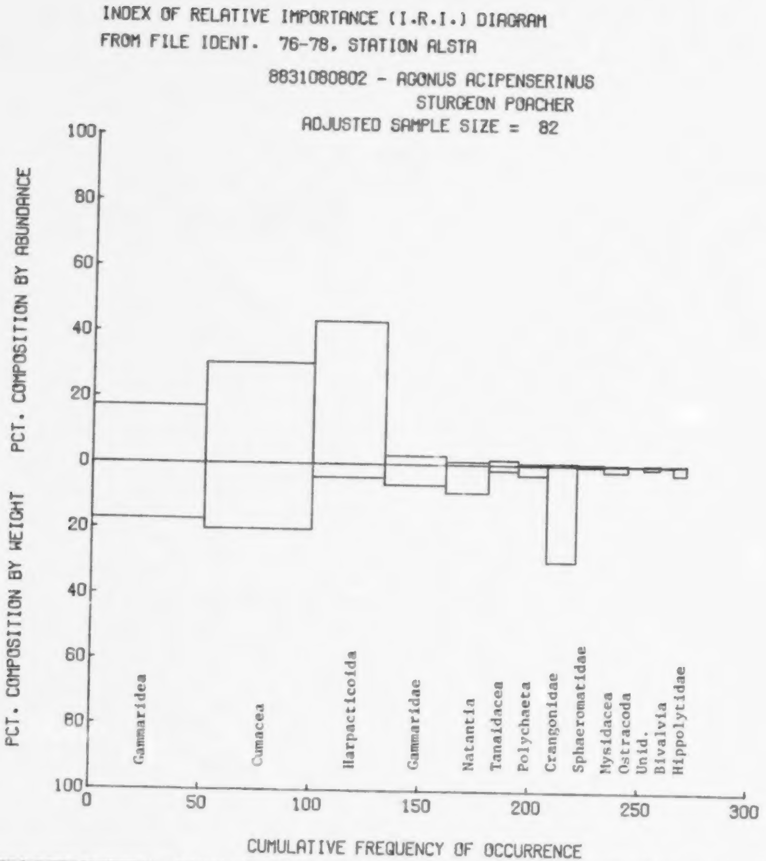


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	50.00	37.50	58.47	4798.7	60.44
MYSIDACEA	33.33	50.00	37.04	2901.2	36.54
SPHAEROMATIDAE	16.67	8.33	3.37	195.0	2.46
UNIDENTIFIED	8.33	4.17	1.12	44.1	.56

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.40	.48	.50
SHANNON-WEINER DIVERSITY	1.52	1.22	1.14
EVENNESS INDEX	.76	.61	.57

Fig. B-54. IRI prey spectrum of tadpole sculpins in neritic waters along Strait of Juan de Fuca.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	51.22	17.33	17.15	1765.9	25.91
CUMACEA	49.78	30.48	20.19	2471.6	36.27
HARPACTICOIDA	32.93	43.31	4.13	1562.2	22.93
GAMMARIDAE	28.05	2.68	6.27	251.3	3.69
NATANTIA	19.51	.92	8.68	187.4	2.75
TANAIDACEA	13.41	1.53	1.74	43.8	.64
POLYCHAETA	13.41	.62	3.10	50.0	.73
CRANGONIDAE	13.41	.68	29.58	406.0	5.96
SPHAEROMATIDAE	12.20	.49	.41	11.0	.16
MYSIDACEA	10.98	.30	1.88	23.9	.35
OSTRACODA	7.32	.09	.08	1.2	.02
UNIDENTIFIED	7.32	.33	.93	9.2	.13
BIVALVIA	6.10	.15	.19	2.0	.03
HIPPOLYTIDAE	6.10	.21	2.64	17.4	.26

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

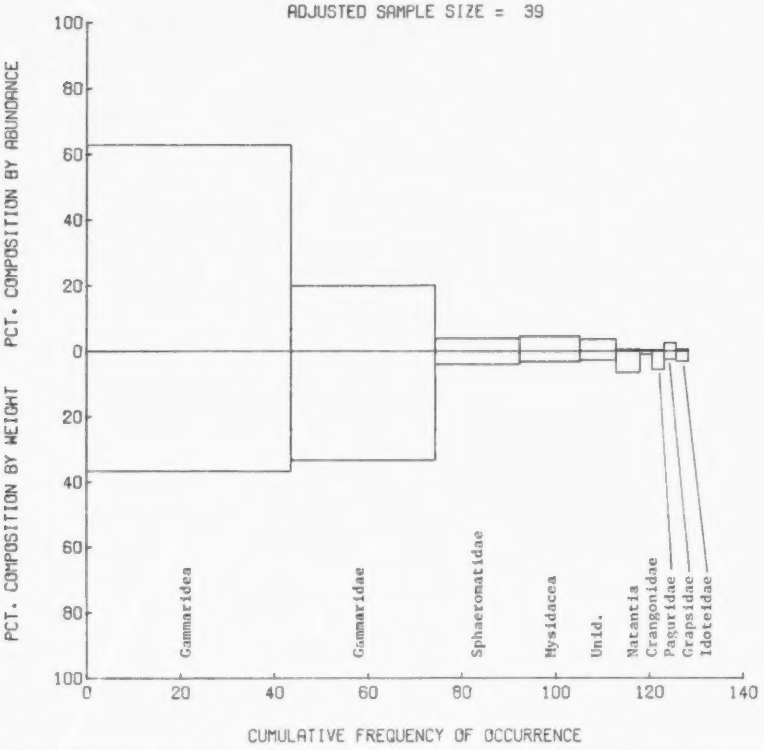
	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.31	.17	.26
SHANNON-WEINER DIVERSITY	2.09	3.02	2.29
EVENNESS INDEX	.44	.64	.49

Fig. B-55. IRI prey spectrum of sturgeon poachers in shallow sublittoral habitats along the Strait of Juan de Fuca.

Reproduced from best available copy.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78. STATION ALSTA

8831090806 - LIPARIS CYCLOPUS
RIBBON SNAILFISH
ADJUSTED SAMPLE SIZE = 39



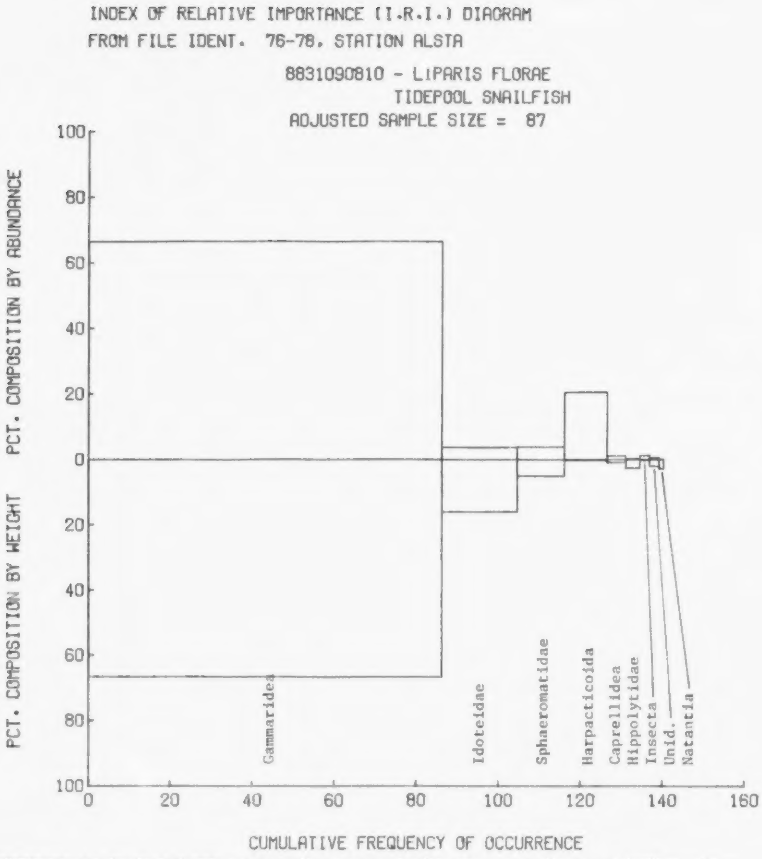
```
                                  FREQ   NUM.   GRAV.  PREY    PERCENT
        PREY ITEM                 OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
 ----------------------------     -----  -----  -----  ------  ---------

GAMMARIDEA                        43.59  62.78  36.65  4334.1    68.29
GAMMARIDAE                        30.77  20.00  33.29  1639.6    25.83
SPHAEROMATIDAE                    17.95   3.89   4.05   142.5     2.25
MYSIDACEA                         12.82   4.44   3.25    98.6     1.55
UNIDENTIFIED                       7.69   3.61   2.78    49.2      .77
NATANTIA                           5.13    .56   6.54    36.4      .57
CRANGONIDAE                        2.56    .28   1.04     3.4      .05
PAGURIDAE                          2.56    .28   5.73    15.4      .24
GRAPSIDAE                          2.56   2.50   2.61    13.1      .21
IDOTEIDAE                          2.56    .56   3.18     9.6      .15

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX             .44    .26                .53
      SHANNON-WEINER DIVERSITY           1.80   2.48               1.26
      EVENNESS INDEX                      .47    .65                .33
```

Fig. B-56. IRI prey spectrum of ribbon snailfish along Strait of Juan de Fuca.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	86.21	66.50	66.55	11469.1	94.08
IDOTEIDAE	18.39	3.72	16.04	363.5	2.98
SPHAEROMATIDAE	11.49	3.85	5.05	102.3	.84
HARPACTICOIDA	10.34	20.41	.29	214.1	1.76
CAPRELLIDEA	4.60	1.09	.91	9.2	.08
HIPPOLYTIDAE	3.45	.19	2.73	10.1	.08
INSECTA	2.30	1.22	.30	3.5	.03
UNIDENTIFIED	2.30	.58	2.15	6.3	.05
NATANTIA	1.15	.06	2.90	3.4	.03

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.49	.47	.89
SHANNON-WEINER DIVERSITY	1.65	1.79	.43
EVENNESS INDEX	.35	.38	.09

Fig. B-57. IRI prey spectrum of tidepool snailfish in littoral habitats along Strait of Juan de Fuca.

Shiner Perch

Shiner perch were relatively common in the nearshore beach seine catches in northern Puget Sound, especially at Deadman and Westcott bays during summer; they were also caught in the townet at Birch Bay, Cherry Point, and Burrows Island. Prey composition was relatively equally divided between a number of epibenthic organisms (Fig. B-58), gammarid amphipods (38.6 percent of total IRI), cumaceans (29.2 percent), and polychaetes (22.2 percent) with caprellid amphipods making a lesser congribution (8.0 percent).

Shiner perch also ranked high among the most abundant species in the collections along the eastern shoreline, being especially common at the Cherry Point (cobble habitat), Padilla Bay (mud/eelgrass), and Legoe Bay (gravel) sites. Compared to the San Juan Islands samples, the prey composition from these collections was considerably less diverse (H' = 2.61 for abundance and H' = 2.60 for biomass, versus H' = 1.53 for abundance and H' = 1.26 for biomass) and was dominated by gammarid amphipods (95.6 percent of total IRI) with only minor contributions by calanoid copepods and isopods (Fig. B-59).

Shiner perch was one of the principal schooling nearshore fishes characterizing the eastern MESA sampling sites along the Strait of Juan de Fuca, especially at Beckett Point and Jamestown. The diverse IRI prey spectrum was composed of gammarid amphipods (47% of total IRI), cumaceans, harpacticoid copepods, tanaids, sphaeromatid isopods (including *Gnorimosphaeroma oregonensis* and *Exosphaeroma amplicauda*), algae, and calanoid copepods (Fig. B-60).

DeMartini (1969) listed bivalve molluscs, gammarid amphipods, tanaids, cumaceans, polychaete annelids and ostracods as the principal prey organisms of shiner perch.

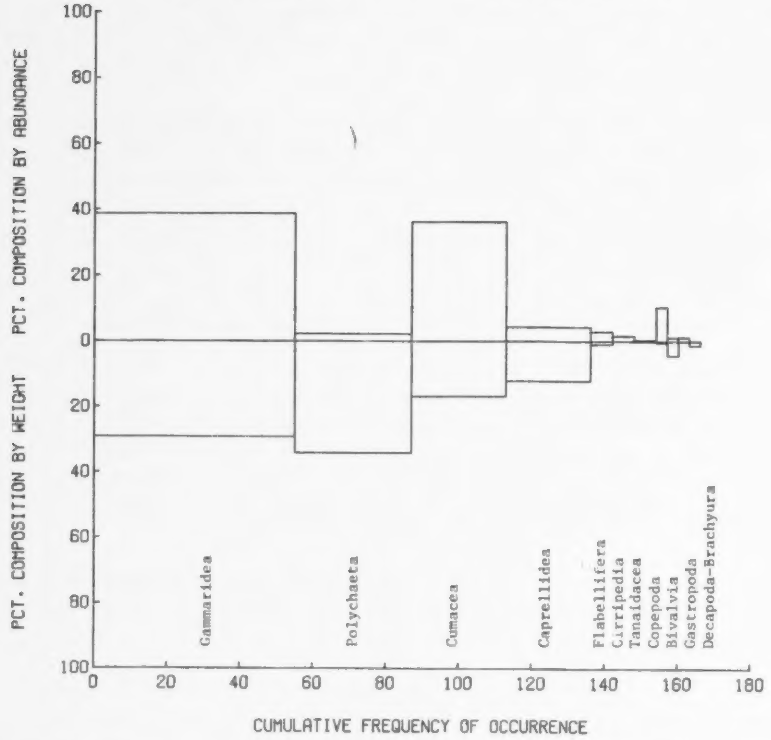
Weller's (1975) analysis of shiner perch food habits in Anaheim Bay, California, indicated that unidentified eggs dominated the prey biomass during all seasons (Table B-12a-d) although topsmelt (*Atherinops affinis*) were somewhat important in the spring, insects and mussels (*Mytilus edulis*) appeared in the summer and fall diets and mussels, polychaetes, gastropods and topsmelt occurred during the winter.

The studies of Bane and Robinson (1970) in upper Newport Bay, California indicated only Potoamogetonaceae plants (includes eelgrass, *Zostera marina*), crustaceans and rocks as the principal prey of shiner perch; this is based, however, only on frequency of occurrence data (Table B-13).

Striped Seaperch

Striped seaperch from northern Puget Sound (Deadman Bay, Guemes Island and Cherry Point) had a prey composition composed almost entirely of epibenthic or benthic crustaceans--gammarid amphipods, valviferan and flabelliferan isopods, crabs and shrimp, while in the Strait of Juan de Fuca (Beckett Point, Twin Rivers, and Morse Creek) over 90% of the striped seaperch prey spectrum was made up of gammarid amphipods, supplemented by sphaeromatid (*Gnorimosphaeroma oregonensis*) and idoteid (*Synidotea nodulosa*) isopods.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. N PGSD, STATION ALSTA
PREDATOR 8835600201 - CYMATOGASTER AGGREGATA
(SHINER PERCH) ADJUSTED SAMPLE SIZE = 31

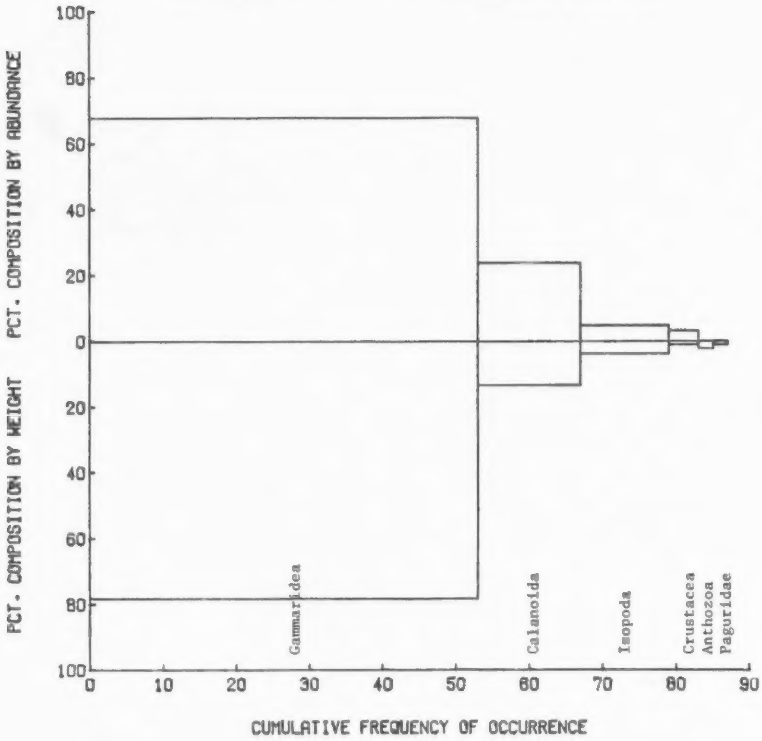


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	55.00	38.82	29.10	18585.6	86.10
POLYCHAETA	32.00	2.17	34.10	1160.6	5.40
CUMACEA	26.00	36.30	16.81	1380.9	6.40
CAPRELLIDEA	23.00	4.31	12.09	377.2	1.70
FLABELLIFERA	6.00	2.90	.95	23.1	.10
CIRRIPEDIA	6.00	1.60	.03	9.8	.00
TANAIDACEA	6.00	.43	.03	2.8	.00
COPEPODA	3.00	10.31	.48	32.4	.20
BIVALVIA	3.00	1.11	4.35	16.4	.10
GASTROPODA	3.00	1.22	.02	3.7	.00
DECAPODA-BRACHYURA	3.00	.05	1.25	3.9	.00

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.30	.25	.75
SHANNON-WEINER DIVERSITY	2.15	2.23	.80
EVENNESS INDEX	.62	.65	.29

Fig. B-58. IRI prey spectrum of shiner perch in northern Puget Sound.



INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. WH BS. STATION ALL
PREDATOR 8835600201 - CYMATOGASTER AGGREGATA
(SHINER PERCH) ADJUSTED SAMPLE SIZE = 51

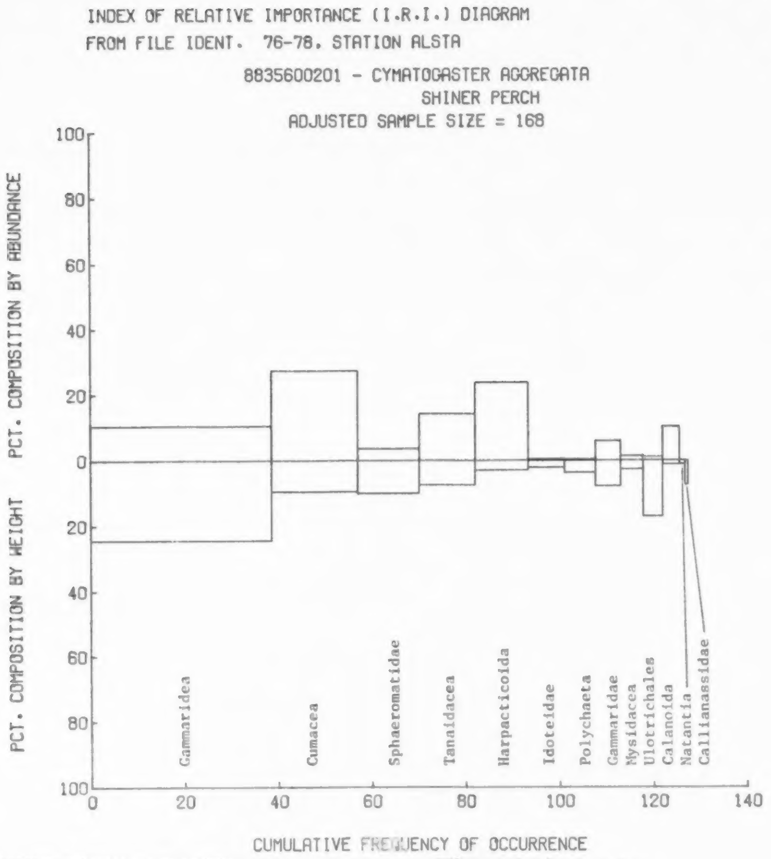
```
                             FREQ   NUM.   GRAV.  PREY     PERCENT
        PREY ITEM            OCCUR  COMP.  COMP.  I.R.I.   TOTAL IRI
 ---------------------------  -----  -----  -----  ------   ---------

GAMMARIDEA                   53.00  67.89  78.31  7748.6     92.30
CALANOIDA                    14.00  23.74  13.38   519.7      6.20
ISOPODA                      12.00   4.74   3.87   103.3      1.20
CRUSTACEA                     4.00   3.14   1.06    16.8       .20
ANTHOZOA                      2.00    .04   2.25     4.6       .00
PAGURIDAE                     2.00    .13   1.06     2.4       .00

  PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
  COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
  (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

     PERCENT DOMINANCE INDEX          .52    .63                .86
     SHANNON-WEINER DIVERSITY        1.25   1.11                .45
     EVENNESS INDEX                   .49    .43                .22
```

Fig. B-59. IRI prey spectrum of shiner perch from shallow sublittoral habitats along the eastern shoreline of northern Puget Sound.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	38.69	10.49	24.43	1351.1	44.51
CUMACEA	18.45	27.31	9.50	679.3	22.38
SPHAEROMATIDAE	13.10	3.61	10.07	179.1	5.90
TANAIDACEA	11.90	14.09	7.45	256.4	8.45
HARPACTICOIDA	11.31	23.70	2.99	301.9	9.95
IDOTEIDAE	7.74	.45	2.18	20.3	.67
POLYCHAETA	6.55	.32	3.75	26.6	.88
GAMMARIDAE	5.36	5.96	7.89	74.2	2.44
MYSIDACEA	4.76	1.35	2.77	19.6	.65
ULOTRICHALES	4.17	.97	17.19	75.7	2.49
CALANOIDA	3.57	10.25	1.24	41.0	1.35
NATANTIA	1.19	.05	1.14	1.4	.05
CALLIANASSIDAE	.60	.03	7.46	4.5	.15

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX		.18	.13		.27
SHANNON-WEINER DIVERSITY		2.85	3.34		2.42
EVENNESS INDEX		.58	.68		.49

Fig. B-60. IRI prey spectrum of shiner perch in the Strait of Juan de Fuca.

Table B-12. Prey composition (gravimetric composition) of shiner perch during spring (a), summer (b), fall (c), and winter (d) in Anaheim Bay, California, documented by Weller(1975).

PREDATOR 8835600201 - CYMATOGASTER AGGREGATA (SHINER PERCH)

a. Spring

INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
FROM FILE IDENT. REF 53. STATION SLSTA
****

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
ENTEROMORPHA					
CHLOROPHYTA			1.70		
TEGULA SP.					
GASTROPODA			1.10		
ULVA SP.					
CAPRELLIDEA					
OLIVELLA SP.					
UNIDENTIFIED EGG			36.90		
MYSIDACEA					
ATHERINOPS AFFINIS			5.00		
PLEOCYEMATA-CARIDEA					
MYTILUS EDULIS			1.30		
AMPHIPODA					
POLYCHAETA			1.10		
COPEPODA					
DIPTERA			3.70		
OSTRACODA					
CRUSTACEA					

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX		.00	.14		.00
SHANNON-WEINER DIVERSITY		.00	1.25		.00
EVENNESS INDEX		.00	.44		.00

b. Summer

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
CAPRELLIDEA					
DIPTERA			6.70		
ENTEROMORPHA					
UNIDENTIFIED EGG			69.70		
PLEOCYEMATA-CARIDEA					
MYSIDACEA					
TEGULA AP.					
MYTILUS EDULIS			5.30		
COPEPODA					
AMPHIPODA					
ULVA SP.					
OSTRACODA					
CRUSTACEA					
OLIVELLA SP.					

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX		.00	.49		.00
SHANNON-WEINER DIVERSITY		.00	.85		.00
EVENNESS INDEX		.00	.54		.00

Table B-12 (continued).

```
PREDATOR  8835600201 - CYMATOGASTER AGGREGATA              (SHINER PERCH          )
```

c. fall

```
              INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
               FROM FILE IDENT. REF 53. STATION SLSTA
              ********************************************

                                      FREQ   NUM.   GRAV.  PREY     PERCENT
            PREY ITEM                 OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   ---------------------------       -----  -----  -----  ------  ---------


   MYSIDACEA
   OLIVELLA SP.
   GASTROPODA                                        .90
   PLEOCYEMATA-CARIDEA
   UNIDENTIFIED EGG                                65.50
   CAPRELLIDEA
   DIPTERA                                          1.70
   ENTEROMORPHA
   MYTILUS EDULIS                                   2.30
   OSTRACODA
   POLYCHAETA                                       1.60
   CRUSTACEA
   AMPHIPODA
   COPEPODA
   ULVA SP.

      PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
      COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
      (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

         PERCENT DOMINANCE INDEX              .00    .43              .00
         SHANNON-WEINER DIVERSITY             .00    .78              .00
         EVENNESS INDEX                       .00    .34              .00
```

d. winter

```
                                      FREQ   NUM.   GRAV.  PREY     PERCENT
            PREY ITEM                 OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   ---------------------------       -----  -----  -----  ------  ---------

   CRUSTACEA
   CHLOROPHYTA                                       .80
   OLIVELLA SP.
   GASTROPODA                                       2.80
   ULVA SP.
   OSTRACODA
   ENTEROMORPHA
   UNIDENTIFIED EGG                                28.70
   TEGULA SP.
   AMPHIPODA
   UROCHORDATA                                       .80
   COPEPODA
   MYTILUS EDULIS                                   8.70
   DIPTERA                                           .10
   POLYCHAETA                                       5.50
   CAPRELLIDEA
   ATHERINOPS AFFINIS                               2.70
   MYSIDACEA
   PLEOCYEMATA-CARIDEA

      PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
      COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
      (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

         PERCENT DOMINANCE INDEX              .00    .09              .00
         SHANNON-WEINER DIVERSITY             .00   1.46              .00
         EVENNESS INDEX                       .00    .49              .00
```

Table B-13. Prey composition (frequency of occurrence) of shiner perch in upper Newport Bay, California, documented by Bane and Robinson(1970).

```
PREDATOR  8835600201 - CYMATOGASTER AGGREGATA                   (SHINER PERCH        )


               INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                FROM FILE IDENT. REF 54, STATION SLSTA
               *******************************************

                                       FREQ   NUM.   GRAV.  PREY     PERCENT
           PREY ITEM                   OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  ---------------------------          -----  -----  -----  ------  ---------

 POTAMOGETONACEAE                      69.00
 CRUSTACEA                             56.00
 ROCK                                  51.00
 RHODOPHYTA
 CHLOROPHYTA
 OSTEICHTHYES
 ANNELIDA
 PHAEOPHYTA

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                .00    .00                .00
      SHANNON-WEINER DIVERSITY               .00    .00                .00
      EVENNESS INDEX                         .00    .00                .00
```

DeMartini's (1969) analysis of the comparative feeding mechanism morphology among the surfperches indicated that bivalve molluscs, acmaeid limpets, the shrimp, Callianassa californiensis, isopods, gammarid amphipods, gastropods (especially Thais sp.) and caridean crustaceans were important prey of striped seaperch.

Gnose's (1967) detailed study of striped seaperch in Yaquina Bay, Oregon, indicated that the gammarid amphipods Amphithoe sp. and Anisogammarus sp. comprised the most frequently eaten prey item (Table B-14); mussels, barnacles, chironomid insects and isopods (Idotea sp.) were of secondary importance. Alevizon (1975) did an extensive comparative study of striped seaperch feeding ecology in southern California. He found that, on the basis of prey biomass, gammarids, polychaete annelids, caridean crustaceans, caprellid amphipods and isopods were equally important at Santa Cruz Island (Table B-15a) while just gammarid and caprellid amphipods and caridean crustaceans were of importance to fish collected along the Santa Barbara shoreline (Table B-15b).

Pile Perch

Pile perch collected in the vicinity of Guemes Island and Cherry Point had consumed mostly valviferan isopods (73.1 percent of the total IRI), bivalves (10.5 percent), crabs (9.7 percent), and gammarid amphipods (4.5 percent). Those collected along the Strait of Juan de Fuca, however, had consumed gastropods (32.1% of the total IRI), pagurid crabs (Pagurus beringanus, P. granosimanus, P. hirsutiusculus; 22.6%), gammarid amphipods, (13.6%), brachyuran crabs, (11.5%), sphaeromatid isopods, (2.6%), valviferan isopods (5.9%) and tanaids, (2.8%).

Pagurid crabs, fissurellid and acmaeid limpets, the bivalves Pododesmus sp., Mytilus sp. and Hinnites sp. and the gastropod Thais sp. were listed as principal prey of pile perch by DeMartini (1969).

Wares (1968) has provided an extensive analysis of prey composition, using frequency of occurrence and estimated percent volume, of pile perch in three regions of Yaquina Bay, Oregon. In general, barnacles (Balanus sp.), mussels (Mytilus sp.), crabs (Cancer magister, C. productus, and C. oregonensis) Other bivalves (Clinocardium sp., Prototheca sp.) and shrimp (Upogebia sp.) were the prevalent food organisms. When examining variations in prey composition by seasons, crabs, particularly Cancer magister, appeared predominantly in the spring while barnacles and mussels comprised the greatest proportion of the diet during the rest of the year. In comparing the three regions of the bay (upper, mid and lower) there were no consistent trends although decapods appeared to be most important in the diet of pile perch occupying the lower bay and bivalves other than mussels appeared predominantly in fish from the upper bay. In general, however, there was no change in feeding ecology, as all prey were epibenthic or benthic organisms which were "picked" from the bottom.

Quast's (1968) documentation of the food habits of pile perch in southern California kelp beds indicated that decapod crustaceans, bivalve molluscs and ophiuroids were the principal prey of all size classes while only gastropods entered significantly into the prey spectra of fish 200-299 mm in length (Table B-16a & b).

Table B-14. Prey composition (frequency of occurrence) of striped seaperch in Yaquina Bay, Oregon, documented by Gnose(1967).

```
PREDATOR  8835600301 - EMBIOTOCA LATERALIS                    (STRIPED SEAPERCH    )


             INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
               FROM FILE IDENT. REF 57. STATION SLSTA
             ******************************************

                                      FREQ   NUM.   GRAV.  PREY     PERCENT
          PREY ITEM                   OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   ----------------------------       -----  -----  -----  ------  ---------

    AMPHITHOE SP.                     90.60
    ANISOGAMMARUS SP.                 90.60
    MYTILUS SP.                       25.60
    BALANUS SP.                       20.50
    DIPTERA-CHIRONOMIDAE              16.20
    IDOTEA SP.                        16.20
    MYTILIDAE                         13.70
    UPOGEBIA SP.                       9.40
    POLYCHAETA                         7.70
    UNIDENTIFIED ALGAE                 6.80
    LITTORINA SP.                      6.00
    CLINOCARDIUM SP.                   4.30
    OSTRACODA                          3.40
    CANCER SP.                         3.40
    MEMBRANIPORA SP.                   3.40
    MACOMA SP.                         2.60
    CUMACEA                            2.60
    COLEOPTERA                         2.60
    CALLIOSTOMA SP.                    1.70
    TIPULIDAE                          1.70
    HYDROZOA                           1.70
    AMPHISSA SP.                        .90
    ACMAEIDAE                           .90
    BUCCINUM SP.                        .90
    LACUNA SP.                          .90
    SILIQUA AP.                         .90

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

          PERCENT DOMINANCE INDEX                .00    .00               .00
          SHANNON-WEINER DIVERSITY               .00    .00               .00
          EVENNESS INDEX                         .00    .00               .00
```

Table B-15. Prey composition (frequency of occurrence and gravimetric compsoition) of striped seaperch at Santa Cruz (a) and Santa Barbara (b), California, documented by Alevizon(1975).

```
PREDATOR  8835600301 - EMBIOTOCA LATERALIS                    (STRIPED SEAPERCH     )


               INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                 FROM FILE IDENT. REF 56. STATION SLSTA
               ******************************************

a.                                   FREQ   NUM.   GRAV.  PREY     PERCENT
         PREY ITEM                   OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   -----------------------------     -----  -----  -----  ------  ---------

   GASTROPODA                        75.00
   ECHINOIDEA                        21.90
   DECAPODA-PLEOCYEMATA              18.80
   GALATHEIDAE                       12.50
   DECAPODA-PLEOCYEMATA              12.50
   ACMAEIDAE                         12.50
   POLYPLACOPHORA                     9.40
   BIVALVIA                           3.10
   OSTEICHTHYES                       3.10
   OPHIUROIDEA                        3.10
   PLEOCYEMATA-CARIDEA                              17.00
   GAMMARIDEA                                       21.00
   IDOTEA SP.                                       10.00
   CAPRELLIDEA                                      14.00
   ISOPODA                                           7.00
   POLYCHAETA                                       18.00

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

       PERCENT DOMINANCE INDEX                     .00    .14                .00
       SHANNON-WEINER DIVERSITY                    .00   2.35                .00
       EVENNESS INDEX                              .00    .91                .00


b.                                   FREQ   NUM.   GRAV.  PREY     PERCENT
         PREY ITEM                   OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   -----------------------------     -----  -----  -----  ------  ---------

   GASTROPODA                        32.20
   DECAPODA-PLEOCYEMATA              22.60
   BIVALVIA                          16.10
   DECAPODA-PLEOCYEMATA              12.90
   UNIDENTIFIED                       9.70
   OPHIUROIDEA                        3.20
   GAMMARIDEA                                       38.00
   PLEOCYEMATA-CARIDEA                              16.00
   CAPRELLIDEA                                      33.00
   POLYCHAETA
   ISOPODA

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

       PERCENT DOMINANCE INDEX                     .00    .28                .00
       SHANNON-WEINER DIVERSITY                    .00   1.48                .00
       EVENNESS INDEX                              .00    .93                .00
```

Table B-16. Prey composition (frequency of occurrence) of pile perch 100-199mm (a) and 200-299mm long (b) in southern California kelp beds documented by Quast(1968).

```
PREDATOR  8835600601 - RHACOCHILUS VACCA                    (PILE PERCH           )


              INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
               FROM FILE IDENT. REF 59, STATION SLSTA
              *********************************************

a.                                   FREQ   NUM.   GRAV.  PREY     PERCENT
        PREY ITEM                    OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  ---------------------------        -----  -----  -----  ------  ---------

  DECAPODA-PLEOCYEMATA               68.00
  BIVALVIA                           68.00
  OPHIUROIDEA                        19.00
  PLEOCYEMATA-CARIDEA                10.00
  BRYOZOA(ECTOPROCTA)                 9.00
  IDOTEA RESECATA                     9.00
  GASTROPODA                           .50
  GAMMARIDEA                           .50
  UNIDENTIFIED ALGAE                   .50

    PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
    COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
    (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                  .00    .00                .00
      SHANNON-WEINER DIVERSITY                 .00    .00                .00
      EVENNESS INDEX                           .00    .00                .00

b.                                   FREQ   NUM.   GRAV.  PREY     PERCENT
        PREY ITEM                    OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
  ---------------------------        -----  -----  -----  ------  ---------

  DECAPODA-PLEOCYEMATA               47.00
  BIVALVIA                           44.00
  GASTROPODA                         25.00
  OPHIUROIDEA                        14.00
  BRYOZOA(ECTOPROCTA)                 6.00
  UNIDENTIFIED ALGAE                  5.00
  GAMMARIDEA                          5.00
  PLEOCYEMATA-CARIDEA                 5.00
  IDOTEA RESECATA                      .50
  CARDIIDAE
  PAGURIDAE
  MYTILUS SP.
  DONAX SP.

    PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
    COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
    (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                  .00    .00                .00
      SHANNON-WEINER DIVERSITY                 .00    .00                .00
      EVENNESS INDEX                           .00    .00                .00
```

Redtail Surfperch

Redtail surfperch occurred abundantly only along the western Strait of Juan de Fuca (Twin Rivers and Hydaka Beach). Over 70% of the prey spectrum was gammarid amphipods. Mysids (including *Neomysis awatschensis*), sphaeromatid isopods (including *Gnorimosphaeroma oregonensis* and *Exosphaeroma* sp.), flabelliferan isopods, idoteid isopods (including *Idotea resecata* and *I. wosnesenski*), and polychaetes were secondary prey (Fig. B-61).

Snake Prickleback

Stomach samples from snake prickleback from northern Puget Sound characterized this species as principally a benthic feeder. Bivalves composed 48.7 percent of the total IRI, tanaids and polychaetes both accounted for 21.2 percent, and gammarids amphipods contributed 7.3 percent.

Oligochaetes accounted for 84.4 percent of the total IRI; gammarid amphipods, 11.0 percent; and polychaetes, 4.6 percent, in stomachs from fish collected in the mud/eelgrass habitat (Fidalgo Bay) near Anacortes.

Gammarid amphipods and harpacticoid copepods were the major prey, based on numbers, and polychaete annelids provided significant contributions to the prey biomass of snake prickleback collected in nearshore habitats of Kodiak Island, Alaska (Harris and Hartt 1977).

High Cockscomb

The most ubiquitous prickleback in littoral habitats along the Strait, *A. purpurescens* was a predominant member of the intertidal assemblage at Slip Point, Observatory Point, Twin Rivers, and Morse Creek. Nemertean worms, gammarid amphipods, and polychaete annelids predominated in the overall prey spectrum (Fig. B-62).

Based on frequency of occurrence, gammarid amphipods, polychaete annelids and gastropod molluscs predominated in the diet of high cockscomb examined from San Simeon, California by Barton (1974) (Table B-17).

Based on frequency of occurrence, Peppar (1965) assessed the diet of high cockscomb collected at Second Narrows, Burrard Inlet, British Columbia. He found algae, polychaete annelids, gammarid amphipods and flatworms to be the most commonly occurring food items (Table B-18).

Black Prickleback

Almost three-quarters of the total prey IRI (Fig. B-63) of black pricklebacks collected during the MESA studies in the Strait were gammarid amphipods. Sabellarid and polychaete worms and several algae were also important.

Anomuran crabs, gammarid amphipods and the alga, *Ulva* sp. were the major constituents, based on frequency of occurrence, of the diet of black prickleback at San Simeon, California (Barton 1973; Table B-19).

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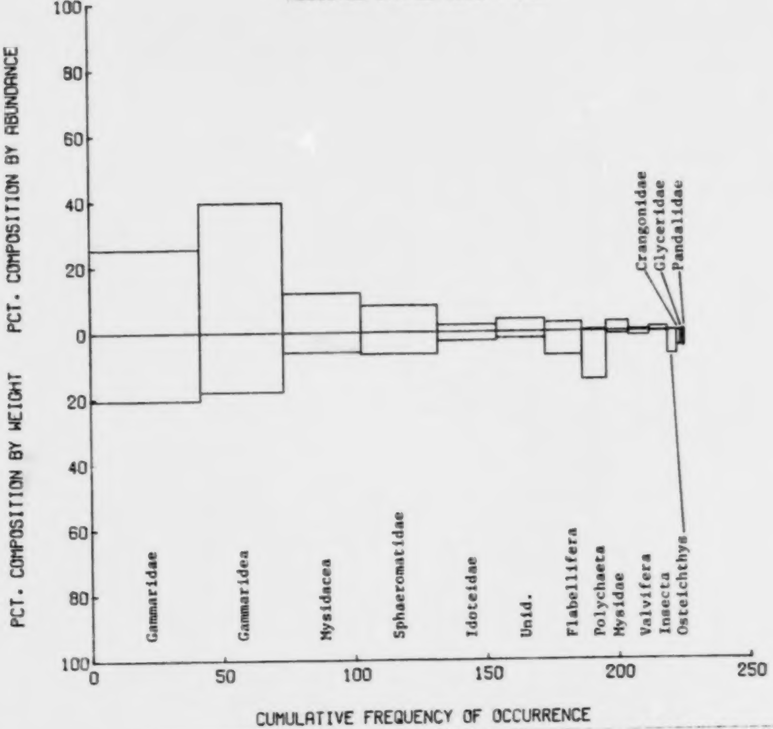
INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA
8835600701 - AMPHISTICUS RHODOTERUS
REDTAIL SURFPERCH
ADJUSTED SAMPLE SIZE = 142



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDAE	41.55	25.43	20.60	1912.2	36.18
GAMMARIDEA	31.69	39.47	17.99	1820.9	34.45
MYSIDACEA	29.58	12.00	6.09	535.2	10.12
SPHAEROMATIDAE	28.87	8.12	6.64	426.3	8.06
IDOTEIDAE	22.54	2.15	2.73	109.9	2.08
UNIDENTIFIED	18.31	3.81	2.03	106.9	2.02
FLABELLIFERA	14.08	2.70	7.24	139.9	2.65
POLYCHAETA	9.15	.42	14.74	138.8	2.63
MYSIDAE	8.45	2.87	.92	32.0	.61
VALVIFERA	7.75	.38	1.46	14.3	.27
INSECTA	7.04	1.21	.17	9.7	.18
OSTEICHTHYS	3.52	.08	7.11	25.3	.48
CRANGONIDAE	1.41	.03	4.60	6.5	.12
GLYCERIDAE	.70	.01	1.45	1.0	.02
PANDALIDAE	.70	.30	4.93	3.7	.07

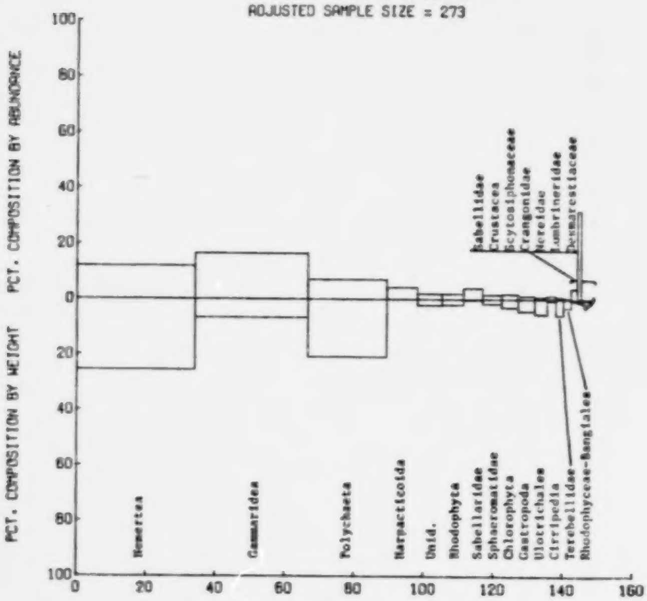
PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.25	.12	.27
SHANNON-WEINER DIVERSITY	2.55	3.41	2.35
EVENNESS INDEX	.56	.74	.51

Fig. B-61. IRI prey spectrum of redtail surfperch in shallow sublittoral habitats along the Strait of Juan de Fuca.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA

8842120402 - ANOPLARCHUS PURPURESCENS
HIGH COCKSCOMB
ADJUSTED SAMPLE SIZE = 273



CUMULATIVE FREQUENCY OF OCCURRENCE

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
NEMERTEA	34.07	11.87	25.50	1272.9	43.11
GAMMARIDEA	32.60	16.28	6.72	749.5	25.38
POLYCHAETA	22.71	6.97	20.86	631.9	21.40
HARPACTICOIDA	8.79	4.19	.08	37.6	1.27
UNIDENTIFIED	6.96	1.99	2.19	29.1	.99
RHODOPHYTA	6.23	1.99	2.02	25.0	.85
SABELLARIDAE	5.49	3.91	.26	22.9	.78
SPHAEROMATIDAE	5.49	1.63	1.75	18.6	.63
CHLOROPHYTA	4.76	1.85	3.03	23.2	.79
GASTROPODA	4.76	1.14	4.36	26.2	.89
ULOTRICHALES	3.66	.71	5.49	22.7	.77
CIRRIPEDIA	2.56	1.21	.54	4.5	.15
TEREBELLIDAE	2.20	.71	5.82	14.3	.49
RHODOPHYCEAE-BANGIALES	2.20	.43	3.23	8.0	.27
SABELLIDAE	1.83	3.77	.81	8.4	.29
CRUSTACEA	1.10	31.77	1.03	36.0	1.22
SCYTOSIPHONACEAE	.73	.14	1.49	1.2	.04
CRANGONIDAE	.73	.14	3.23	2.5	.08
NEREIDAE	.73	.14	2.33	1.8	.06
LUMBRINERIDAE	.37	.07	1.41	.5	.02
DESMARESTIACEAE	.37	.14	1.72	.7	.02
NATANTIA	.37	.07	1.03	.4	.01
STYLOMMATOPHORA-AULACOPODA	.37	1.14	.14	.5	.02

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

		NUM. COMP.	GRAV. COMP.		PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX		.15	.13		.30
SHANNON-WEINER DIVERSITY		3.61	3.83		2.24
EVENNESS INDEX		.62	.66		.39

Fig. B-62. IRI prey spectrum of high cockscomb in littoral habitats along the Strait of Juan de Fuca.

Table B-17. Prey composition (frequency of occurrence) of high cockscomb at San Simeon, California, documented by Barton(1974).

```
PREDATOR 8842120402 - ANOPLARCHUS PURPURESCENS              (HIGH COCKSCOMB       )


          INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
            FROM FILE IDENT. REF 55, STATION SLSTA
          ********************************************

                                     FREQ   NUM.   GRAV.  PREY     PERCENT
          PREY ITEM                  OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
 ---------------------------        -----  -----  -----  ------  ---------

   GAMMARIDEA                        44.00
   POLYCHAETA                        40.00
   GASTROPODA                        40.00
   UNIDENTIFIED                      24.00
   DECAPODA-BRACHYURA                12.00
   PHYLLOSPADIX SP.                   8.00
   ANOMURA                            4.00
   BIVALVIA                           4.00

    PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
    COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
    (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX              .00    .00                 .00
      SHANNON-WEINER DIVERSITY             .00    .00                 .00
      EVENNESS INDEX                       .00    .00                 .00
```

Table B-18. Prey composition (frequency of occurrence) of high cockscomb at Second Narrows, Burrard Inlet, B.C., documented by Pepper (1965).

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PREDATOR  8842120402 - ANOPLARCHUS PURPURESCENS             (HIGH COCKSCOMB      )


               INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                 FROM FILE IDENT. REF 60. STATION SLSTA
               *********************************************

                                   FREQ   NUM.   GRAV.  PREY     PERCENT
           PREY ITEM               OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   ----------------------------    -----  -----  -----  ------  ---------

  UNIDENTIFIED ALGAE               32.40
  POLYCHAETA                       17.50
  GAMMARIDEA                       15.60
  PLATYHELMINTHES                  12.60
  NEMERTEA                          5.50
  UNIDENTIFIED                      4.20
  MYTILIDAE                         3.40
  PLEOCYEMATA-CARIDEA               2.90
  ISOPODA                           2.90
  NEREIDAE                          2.10
  LITTORINIDAE                       .80

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

        PERCENT DOMINANCE INDEX             .00    .00              .00
        SHANNON-WEINER DIVERSITY            .00    .00              .00
        EVENNESS INDEX                      .00    .00              .00
```
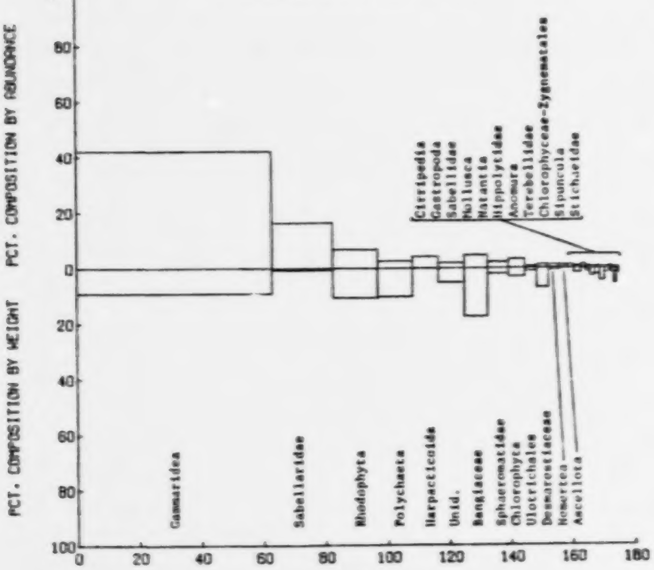

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78. STATION ALSTA

8842121401 - XIPHISTER ATROPURPUREUS
BLACK PRICKLEBACK
ADJUSTED SAMPLE SIZE = 132



CUMULATIVE FREQUENCY OF OCCURRENCE

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	62.88	42.01	9.04	3209.8	73.39
SABELLARIIDAE	19.70	16.32	.66	334.6	7.65
RHODOPHYTA	14.39	6.74	10.68	249.5	5.70
POLYCHAETA	11.36	2.63	10.20	145.8	3.33
HARPACTICOIDA	8.33	4.11	.01	34.4	.79
UNIDENTIFIED	8.33	1.94	5.10	58.7	1.34
BANGIACEAE	7.58	4.68	17.31	166.4	3.81
SPHAEROMATIDAE	6.82	2.17	2.07	28.9	.66
CHLOROPHYTA	5.30	3.20	3.10	33.4	.76
ULOTRICHALES	3.79	.57	1.10	6.3	.15
DESMARESTIACEAE	3.79	1.14	7.08	31.1	.71
NEMERTEA	3.79	1.03	.70	6.5	.15
ASELLOTA	2.27	1.03	.05	2.5	.06
CIRRIPEDIA	2.27	1.03	.00	2.3	.05
GASTROPODA	2.27	.57	1.83	5.5	.12
SABELLIDAE	1.52	1.14	.04	1.8	.04
MOLLUSCA	1.52	.46	1.31	2.7	.06
NATANTIA	1.52	.23	2.92	4.8	.11
HIPPOLYTIDAE	1.52	.34	2.41	4.2	.10
ANOMURA	1.52	.23	4.67	7.4	.17
TEREBELLIDAE	1.52	.23	1.69	2.9	.07
CHLOROPHYCEAE-ZYGNEMATALES	.76	.57	1.03	1.2	.03
SIPUNCULA	.76	.11	1.88	1.5	.03
STICHAEIDAE	.76	.11	5.74	4.4	.10
PHOLIDIDAE	.76	.11	2.06	1.6	.04

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.22	.08	.55
SHANNON-WEINER DIVERSITY	3.36	4.24	1.67

Fig. B-63. IRI prey spectrum of black prickleback in littoral habitats along the Strait of Juan de Fuca.

Table B-19. Prey composition (frequency of occurrence) of black prickleback at San Simeon, California, documented by Barton(1973).

```
PREDATOR  8842121401 - XIPHISTER ATROPURPUREUS               (BLACK PRICKLEBACK    )


              INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
               FROM FILE IDENT. REF 55. STATION SLSTA
              *********************************************

                                        FREQ   NUM.   GRAV.  PREY     PERCENT
         PREY ITEM                      OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   ----------------------------         -----  -----  -----  ------  ---------

   ANOMURA                              28.00
   GAMMARIDEA                           24.00
   ULVA SP.                             16.00
   ISOPODA                               8.00
   GIGARTINA                             4.00
   SMITHORA SP.                          4.00
   GASTROPODA                            4.00
   POLYCHAETA                            4.00
   FLABELLIFERA
   PAGURUS SP.
   PETROLISTHES SP.

     PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
     COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
     (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

        PERCENT DOMINANCE INDEX                .00    .00                .00
        SHANNON-WEINER DIVERSITY               .00    .00                .00
        EVENNESS INDEX                         .00    .00                .00
```

Rock Prickleback

Although not as prevalent in intertidal collections as the black prickleback, the rock prickleback occurred at most of the intertidal sites along the Strait of Juan de Fuca and were common at Slip Point and Twin Rivers. Numerically, the IRI prey spectrum of rock pricklebacks (Fig. B-64) was more diverse than that of black pricklebacks. Gammarid amphipods were the predominant prey organism but composed less than half of the total IRI. Instead, algae made a greater contribution; Rhodophyta, Chlorophyta, Phaephyta, Ultrichales, Bangiales, and Gigartinacea combining for 44.8% of the total IRI.

Algae, principally Smithora sp., Ulva sp. and Plocamium sp., were also the pricnipal diet constituents, based on frequency of occurrence, of rock prickleback collected at San Simeon, California (Barton 1974); gammarid amphipods were the only prey animals (Table B-20).

Ribbon Prickleback

A ribbon prickleback from beach seine collection in northern Puget Sound had 14 gammarid amphipods in its stomach.

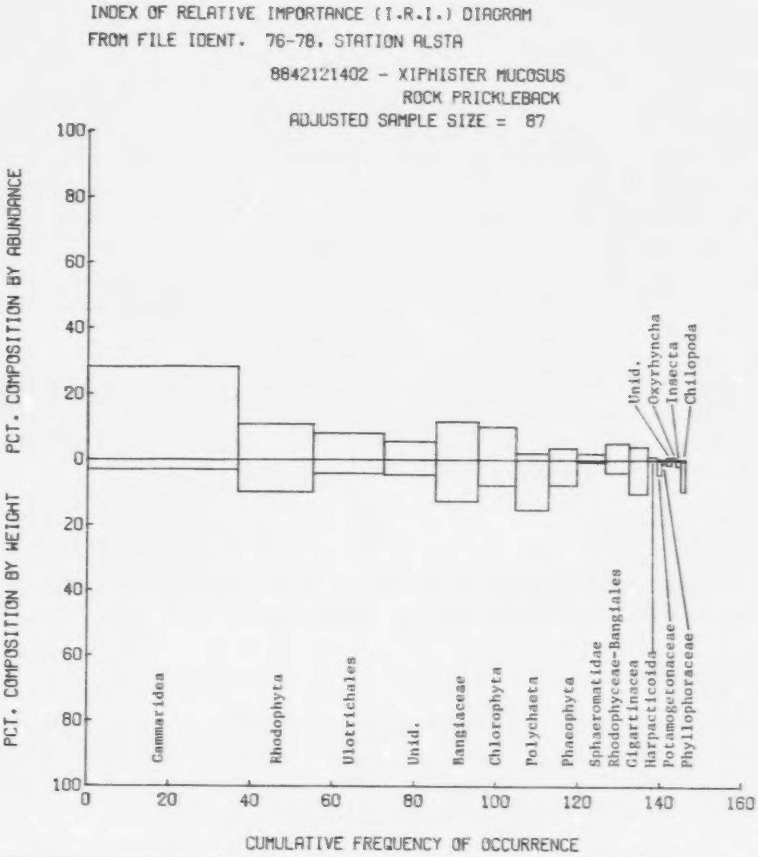
Penpoint Gunnel

Penpoint gunnel from gravel pocket beaches in northern Puget Sound had consumed oniscoidean isopods and gammarid amphipods (43.8% and 43.4% of the total IRI, respectively), valviferan isopods (9.3%), shrimp (1.2%), and several other epibenthic crustacean taxa.

Penpoint gunnels also appeared frequently in both beach seine and tidepool collections along the Strait of Juan de Fuca and were most numerous at Twin Rivers and Beckett Point. Epibenthic crustaceans--gammarid amphipods, harpacticoid copepods, mysids, and valviferan isopods (Idotea sp.)--were the most important prey in the spectrum (Fig. B-65), composing 88% of the total IRI. Benthic polychaete and nemertean worms composed 7.4%.

Crescent Gunnel

As with the penpoint gunnel, crescent gunnel in northern Puget Sound preyed upon epibenthic and benthic organisms. Gammarid amphipods were the principal prey item, totaling 78.4 percent of total IRI. Harpacticoid copepods were less important, accounting for 10.2 percent. Tanaids made up 4.7 percent; polychaetes, 2.5 percent; valviferan isopods, 1.1 percent; and a variety of epibenthic crustaceans contributed less than 1.0 percent of the total IRI. The diet composition of crescent gunnels from the eastern shoreline was quite similar to those in FRI's San Juan Island collections. Gammarid amphipods predominated (85.4 percent of total IRI), while polychaetes (8.8 percent), crab larvae (2.7 percent), and hyperiid and caprellid amphipods (each at 1.1 percent) were the less important prey.



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	36.78	26.21	3.09	1151.3	43.01
RHODOPHYTA	18.39	10.83	9.78	379.1	14.16
ULOTRICHALES	17.24	8.06	4.19	211.2	7.89
UNIDENTIFIED	12.64	5.54	4.60	128.2	4.79
BANGIACEAE	10.34	11.59	12.60	250.2	9.35
CHLOROPHYTA	9.20	10.08	7.83	164.6	6.15
POLYCHAETA	8.05	2.02	15.22	138.7	5.18
PHAEOPHYTA	6.90	3.53	7.69	77.3	2.89
SPHAEROMATIDAE	6.90	2.02	.52	17.5	.65
RHODOPHYCEAE-BANGIALES	5.75	5.04	3.85	51.1	1.91
GIGARTINAC EA	4.60	4.03	10.24	65.6	2.45
HARPACTICOIDA	2.30	1.01	.00	2.3	.09
POTAMOGETONACEAE	1.15	.25	4.54	5.5	.21
PHYLLOPHORACEAE	1.15	.25	1.01	1.4	.05
UNIDENTIFIED	1.15	1.01	1.56	2.9	.11
OXRHYNCHA	1.15	1.01	.00	1.2	.04
INSECTA	1.15	.25	1.77	2.3	.09
CHILOPODA	1.15	.25	9.56	11.3	.42

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

		NUM. COMP.	GRAV. COMP.		PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX		.13	.09		.23
SHANNON-WEINER DIVERSITY		3.55	3.74		2.79
EVENNESS INDEX		.73	.77		.58

Fig. B-64. IRI prey spectrum of rock prickleback in littoral habitats along Strait of Juan de Fuca.

Table B-20. Prey composition (frequency of occurrence) of rock prickleback at San Simeon, California, documented by Barton(1974).

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PREDATOR  8842121402 - XIPHISTER MUCOSUS                        (ROCK PRICKLEBACK


              INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
                FROM FILE IDENT. REF 55. STATION SLSTA
              ****************************************

                                      FREQ   NUM.   GRAV.  PREY      PERCENT
          PREY ITEM                   OCCUR  COMP.  COMP.  I.R.I.  TOTAL IRI
   ----------------------------       -----  -----  -----  ------  ---------

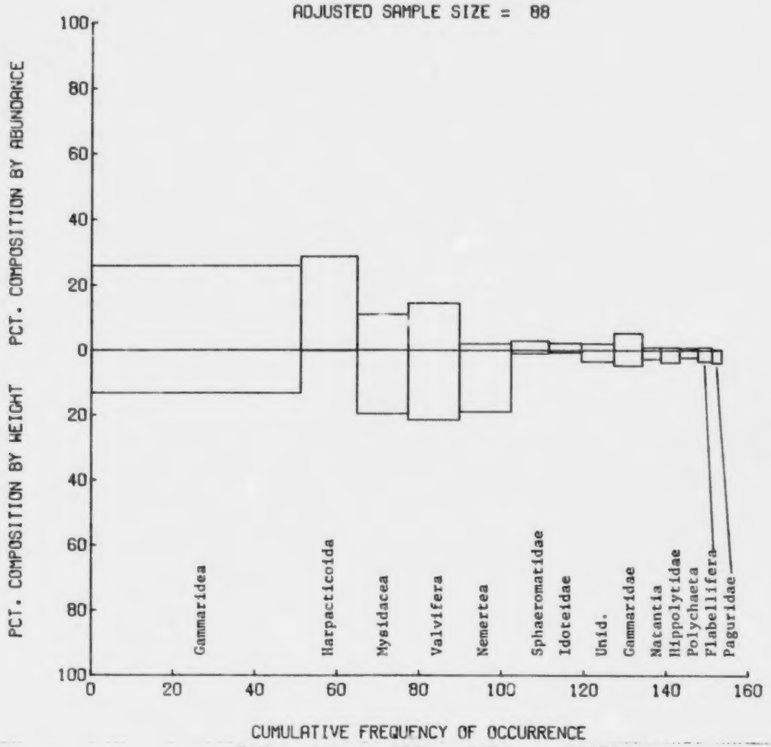
  SMITHORA SP.                        44.00
  ULVA SP.                            44.00
  PLOCAMIUM SP.                       12.00
  GAMMARIDEA                           4.00
  RHODOGLOSSUM SP.                     4.00
  CLADOPHORA SP.                       4.00
  PHYLLOSPADIX SP.                     4.00

    PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
    COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
    (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

       PERCENT DOMINANCE INDEX               .00    .00                 .00
       SHANNON-WEINER DIVERSITY              .00    .00                 .00
       EVENNESS INDEX                        .00    .00                 .00
```

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA

8842130101 - APODICHTHYS FLAVIDUS
PENPOINT GUNNEL
ADJUSTED SAMPLE SIZE = 88



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	51.14	25.96	13.22	2003.7	53.60
HARPACTICOIDA	13.64	28.75	.23	395.2	10.57
MYSIDACEA	12.50	10.96	19.54	381.3	10.20
VALVIFERA	12.50	14.33	21.38	446.4	11.94
NEMERTEA	12.50	2.02	18.92	261.7	7.00
SPHAEROMATIDAE	9.09	2.88	.98	35.1	.94
IDOTEIDAE	7.95	2.21	.73	23.4	.63
UNIDENTIFIED	7.95	2.02	3.55	44.3	1.19
GAMMARIDAE	6.82	5.19	4.75	67.8	1.81
NATANTIA	4.55	.87	2.71	16.2	.43
HIPPOLYTIDAE	4.55	.87	3.78	21.1	.56
POLYCHAETA	4.55	.67	2.31	13.6	.36
FLABELLIFERA	3.41	.87	3.44	14.7	.39
PAGURIDAE	2.27	.19	3.96	9.4	.25

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.19	.15	.33
SHANNON-WEINER DIVERSITY	2.92	3.14	2.26
EVENNESS INDEX	.64	.68	.49

Fig. B-65. IRI prey spectrum of penpoint gunnel in Strait of Juan de Fuca.

In the Strait of Juan de Fuca, crescent gunnels were common in intertidal collections at Twin Rivers, Morse Creek, and North Beach and beach seine collections at Twin Rivers which all contained crescent gunnel. Except for dipteran insects, all the major prey organisms were epibenthic crustaceans. Gammarid amphipods composed over 80% of the IRI; isopods (including sphaeromatid, idoteid, and valviferan species), 7.4%, munnid crabs, 3.4%; and harpacticoid copepods, 2.7% (Fig. B-66).

Saddleback Gunnel

Saddleback gunnels occurred in the same habitats in northern Puget Sound and had much of the same prey composition as the more common crescent gunnel. Amphipods were also the principal prey (49.7 percent of the total IRI) but oniscoidean isopods (not found in *P. laeta* stomachs) ranked a close second (32.9 percent) in importance. Polychaete annelids (7.4 percent), harpacticoid copepods (5.6 percent), cumaceans (2.0 percent), and valviferan isopods (2.0 percent) were also in these stomachs.

In the Strait of Juan de Fuca, gammarid amphipods were important to the diet (75% of the total IRI); secondary prey were sabellid worms, mysids, and juvenile hippolytid shrimp (Fig. B-67).

Pacific Sand Lance

Over both northern Puget Sound and the Strait of Juan de Fuca, Pacific sand lance were similar in occurrence and distribution to juvenile Pacific herring. In the former region, beach seine catches of Pacific sand lance were most frequent and numerous at Eagle Cove, and townet catches, at Point George and Westcott Bay. Along the Strait, both beach seine and townet collections at Dungeness Spit and Kydaka Beach yielded high numbers.

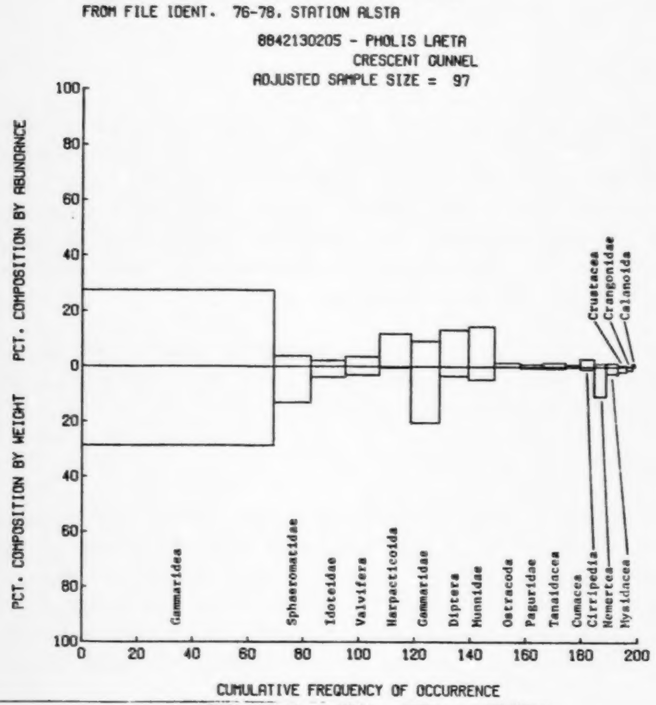
Pacific sand lance were basically pelagic feeders with an even more specialized prey spectrum than juvenile Pacific herring. In northern Puget Sound calanoid copepods composed 88.5 percent of total IRI and gammarid amphipods 9.0 percent. The prey spectrum from the Strait of Juan de Fuca was even more oriented toward calanoid copepods (Fig. B-68).

Over 75% of the prey biomass of Pacific sand lance collected in nearshore habitats at Kodiak Island, Alaska, consisted of calanoid copepods, supplemented by crustacean zoea and nauplii and larvaceans (Harris and Hartt 1977).

Calanoid copepods are, in fact, the almost universal prey organism of all other sand lance species (*Ammodytes americanus*, *A. dubius*, *A. marinus*. *A. tobianus* and *A. personatus*) occurring in north temperate waters of the Atlantic and Pacific Oceans (Meyer et al. 1979; Reay 1970; Scott 1973; Sekiguchi 1977; Senta 1965).

Speckled Sanddab

Speckled sanddabs from the Strait of Juan de Fuca (Beckett Point) contained principally polychaetes and gammarid amphipods. Other less commonly utilized prey included bivalves and their siphons, calanoid copepods, shrimp,

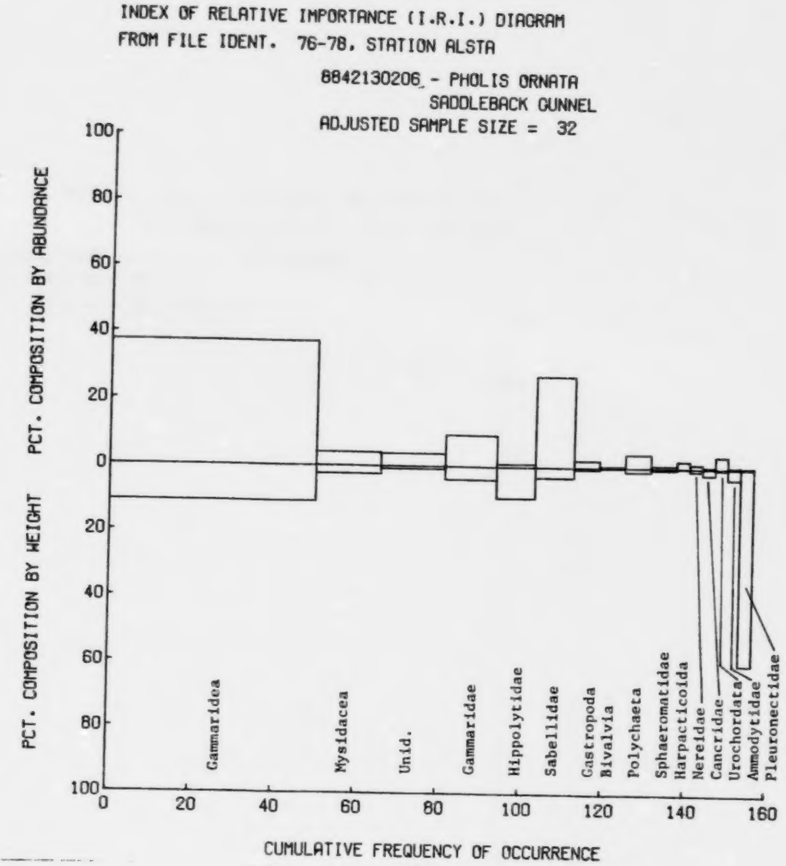


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	69.07	27.45	28.68	3876.6	74.36
SPHAEROMATIDAE	13.40	3.78	13.11	226.5	4.34
IDOTEIDAE	12.37	2.15	3.96	75.6	1.45
VALVIFERA	12.37	3.56	3.11	82.5	1.58
HARPACTICOIDA	11.34	11.87	.41	139.3	2.67
GAMMARIDAE	10.31	9.20	20.40	305.1	5.85
DIPTERA	10.31	13.28	3.49	172.9	3.32
MUNNIDAE	9.28	14.47	4.76	178.4	3.42
OSTRACODA	9.28	1.41	.05	13.6	.26
PAGURIDAE	8.25	.89	.52	11.6	.22
TANAIDACEA	8.25	1.41	.69	17.3	.33
CUMACEA	5.15	.67	.14	4.2	.08
CIRRIPEDIA	5.15	2.82	.98	19.6	.38
NEMERTEA	4.12	1.04	10.78	48.7	.93
MYSIDACEA	4.12	1.26	2.56	15.7	.30
CRUSTACEA	3.09	.52	1.89	7.4	.14
CRANGONIDAE	2.06	.30	1.28	3.2	.06
CALANOIDA	1.03	1.11	.01	1.2	.02

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX	.14	.16	.56
SHANNON-WEINER DIVERSITY	3.40	3.21	1.65
EVENNESS INDEX	.69	.66	.34

Fig. B-66. IRI prey spectrum of crescent gunnel in shallow sublittoral habitats along Strait of Juan de Fuca.

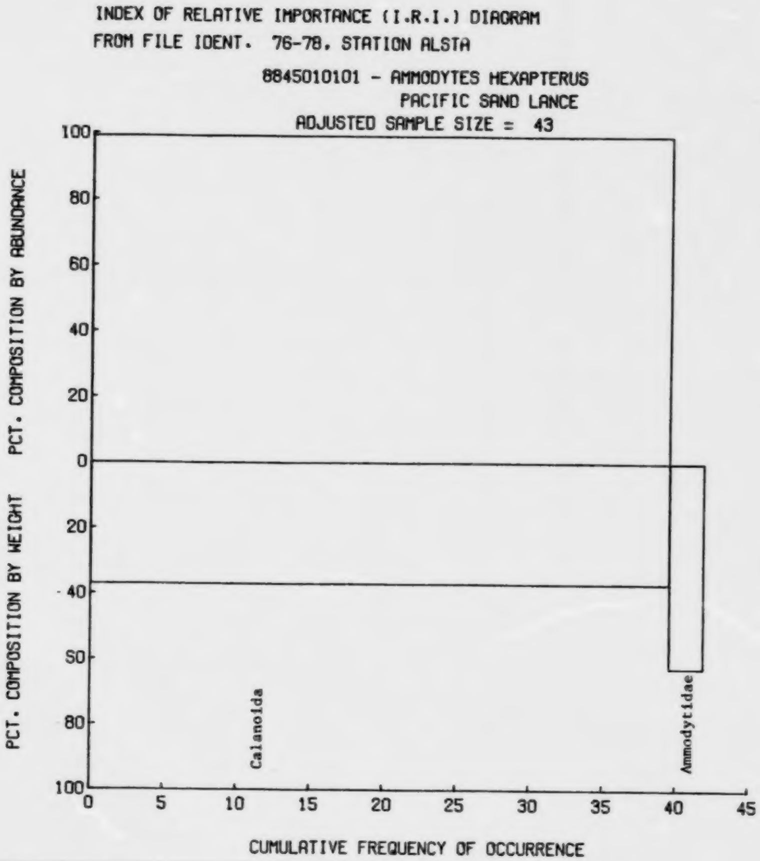


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	50.00	37.47	10.94	2420.4	70.20
MYSIDACEA	15.63	4.06	2.46	101.9	2.95
UNIDENTIFIED	15.63	3.82	.80	72.2	2.09
GAMMARIDAE	12.50	9.55	4.00	169.3	4.91
HIPPOLYTIDAE	9.38	.95	9.53	98.3	2.85
SABELLIDAE	9.38	27.45	3.23	287.6	8.34
GASTROPODA	6.25	2.15	.54	16.8	.49
BIVALVIA	6.25	.48	.04	3.2	.09
POLYCHAETA	6.25	4.06	1.28	33.3	.97
SPHAEROMATIDAE	6.25	.72	.51	7.7	.22
HARPACTICOIDA	3.13	2.15	.00	6.7	.19
NEREIDAE	3.13	1.19	.93	6.6	.19
CANCRIDAE	3.13	.48	1.98	7.7	.22
UROCHORDATA	3.13	3.58	.32	12.2	.35
AMMODYTIDAE	3.13	.48	3.26	11.7	.34
PLEURONECTIDAE	3.13	.24	60.09	188.5	5.47

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.23	.39	.51
SHANNON-WEINER DIVERSITY	2.75	2.18	1.77
EVENNESS INDEX	.65	.51	.42

Fig. B-67. IRI prey spectra of saddleback gunnel in shallow sublittoral habitats along Strait of Juan de Fuca.



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                                       FREQ   NUM.   GRAV.   PREY     PERCENT
           PREY ITEM                   OCCUR  COMP.  COMP.   I.R.I.  TOTAL IRI
 ----------------------------------    -----  -----  -----   ------  ---------

 CALANOIDA                             39.53  99.21  37.06   5387.6    97.32
 AMMODYTIDAE                            2.33    .02  62.69    145.8     2.63

   PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

      PERCENT DOMINANCE INDEX                .98    .53                  .95
      SHANNON-WEINER DIVERSITY               .08    .98                  .18
      EVENNESS INDEX                         .03    .35                  .06
```

Fig. B-68. IRI prey spectrum of Pacific sand lance in Strait of Juan de Fuca.

amomuran crabs, one isopod, and algae.

Pacific Sanddab

Winter beach seine collections at Dungeness Spit and Beckett Point produced Pacific sanddabs. Gammarid amphipods were common prey to three, contributing 68.4 percent of the prey and 3.8 percent of the prey biomass. Mysids (Neomysis sp.), shrimp (61.2 percent total biomass), and polychaetes were the other prey items.

Rock Sole

Adult rock sole were caught, though not in abundance, in the cobble and sand/eelgrass habitats of southwestern San Juan Island. The prey spectrum from northern Puget Sound was extremely broad. Prey items, in descending order of importance, were flabelliferan isopods, gammarid amphipods, bivalve siphons, polychaetes, cumaceans, bivalves, brachyuran crabs, and fish. Rock sole from collections at two Guemes Island sites and Cherry Point along the eastern shoreline had consumed principally gammarid amphipods (88.9 percent of total IRI); crabs (4.4 percent), bivalves (3.0 percent), and polychaetes (2.4 percent) were only supplemental organisms.

Rock sole in the Strait of Juan de Fuca were benthic feeders, preying principally on polychaete annelids (75% of the total IRI) (Fig. B-69). Epibenthic gammarid amphipods (12.6%) and tanaids supplemented the diet.

On the basis of biomass, fish (Pacific sand lance) were more prominent in the diet of rock sole collected in the nearshore environs of Kodiak Island, Alaska, although gammarid amphipods, polychaete annelids and bivalves were important numerically (Harris and Hartt 1977).

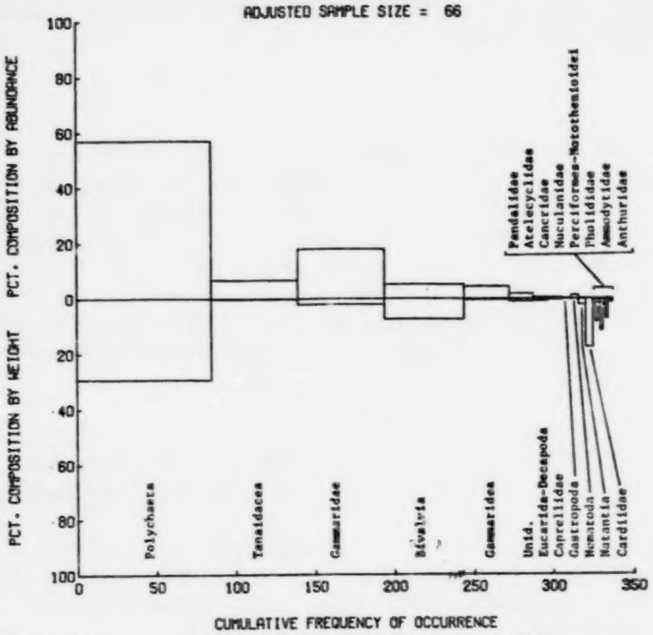
English Sole (Juveniles)

Juvenile English sole were the most frequently caught species of the nearshore demersal assemblages in northern Puget Sound, and were most prevalent at Westcott Bay (mud/eelgrass) and Eagle Cove (sand/eelgrass). Overall, cumaceans dominated the prey spectrum with 74.8 percent of the total IRI (Fig. B-70). Gammarid amphipods (11.7 percent), polychaete annelids (8.8 percent), tanaids (1.1 percent), crabs (1.0 percent), and bivalves (0.3 percent) were of secondary importance. Juvenile English sole were also common in sand/eelgrass and mud/eelgrass habitats along the eastern shoreline. All the prey taxa were similar; diet composition in this region was dominated by gammarid amphipods (87.7 percent of total IRI), with cumaceans (8.4 percent), polychaetes (2.0 percent), and bivalves (1.4 percent) providing lower inputs (Fig. B-71).

Juvenile English sole were the most widely and evenly distributed species at the eight beach seine sites sampled by the MESA program in the Strait of Juan de Fuca. The overall prey spectrum (Fig. B-72) was equally divided among benthic glycerid and gonaid polychaetes, bivalves (including Clinocardium nuttalli), epibenthic gammarid amphipods, cumaceans, harpacticoids, tanaids, and mysids (including Archaeomysis grebnitzki).

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78. STATION ALSTA

8857040801 - LEPIDOPSETTA BILINEATA
ROCK SOLE
ADJUSTED SAMPLE SIZE = 66

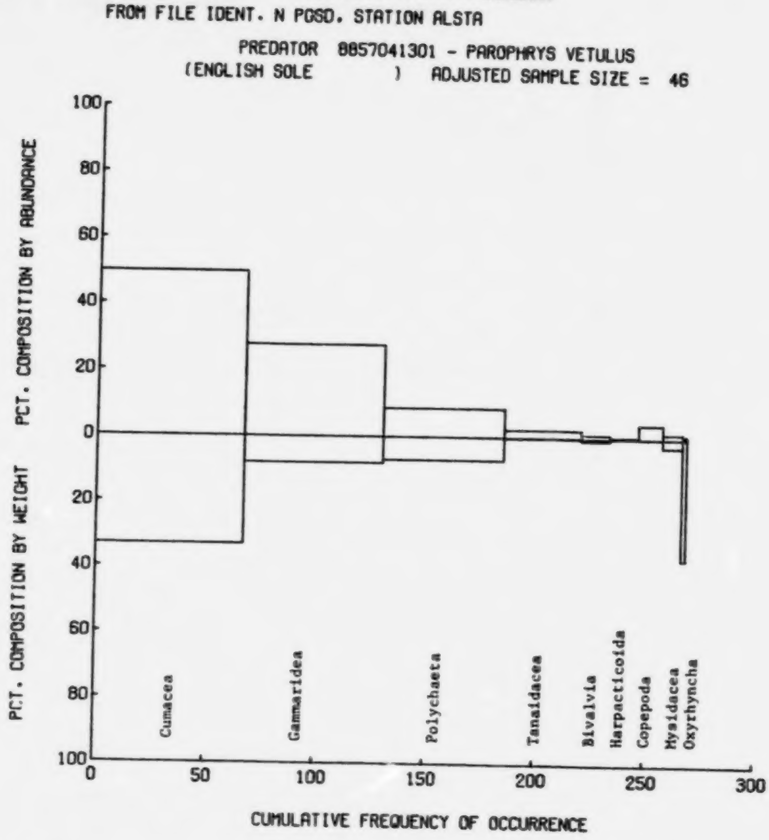


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
POLYCHAETA	84.85	56.91	29.36	7319.5	74.84
TANAIDACEA	54.55	6.68	.20	375.0	3.83
GAMMARIDAE	54.55	17.96	2.06	1091.2	11.15
BIVALVIA	50.00	5.11	7.37	624.1	6.38
GAMMARIDEA	28.79	4.41	.41	138.8	1.42
UNIDENTIFIED	15.15	1.80	1.01	42.6	.44
EUCARIDA-DECAPODA	9.09	.46	.94	12.7	.13
CAPRELLIDAE	9.09	.46	.35	7.4	.08
GASTROPODA	6.06	.23	.01	1.5	.02
NEMATODA	4.55	1.28	.08	5.8	.06
NATANTIA	4.55	.23	2.15	10.9	.11
CARDIIDAE	4.55	.23	17.49	80.6	.82
PANDALIDAE	1.52	.12	1.77	2.9	.03
ATELECYCLIDAE	1.52	.06	8.31	12.7	.13
CANCRIDAE	1.52	.12	1.67	2.7	.03
NUCULANIDAE	1.52	.06	11.51	17.5	.18
PERCIFORMES-NOTOTHENIOIDEI	1.52	.06	2.14	3.3	.03
PHOLIDIDAE	1.52	.12	7.18	11.1	.11
AMMODYTIDAE	1.52	.17	1.42	2.4	.02
ANTHURIDAE	1.52	.12	1.30	2.1	.02

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.37	.15		.58
SHANNON-WEINER DIVERSITY		2.29	3.36		1.39
EVENNESS INDEX		.42	.62		.26

Fig. B-69. IRI prey spectrum of rock sole in shallow sublittoral habitats along Strait of Juan de Fuca.



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                                  FREQ   NUM.   GRAV.  PREY     PERCENT
         PREY ITEM                OCCUR  COMP.  COMP.  I.R.I.   TOTAL IRI
    ---------------------------   -----  -----  -----  ------   ---------

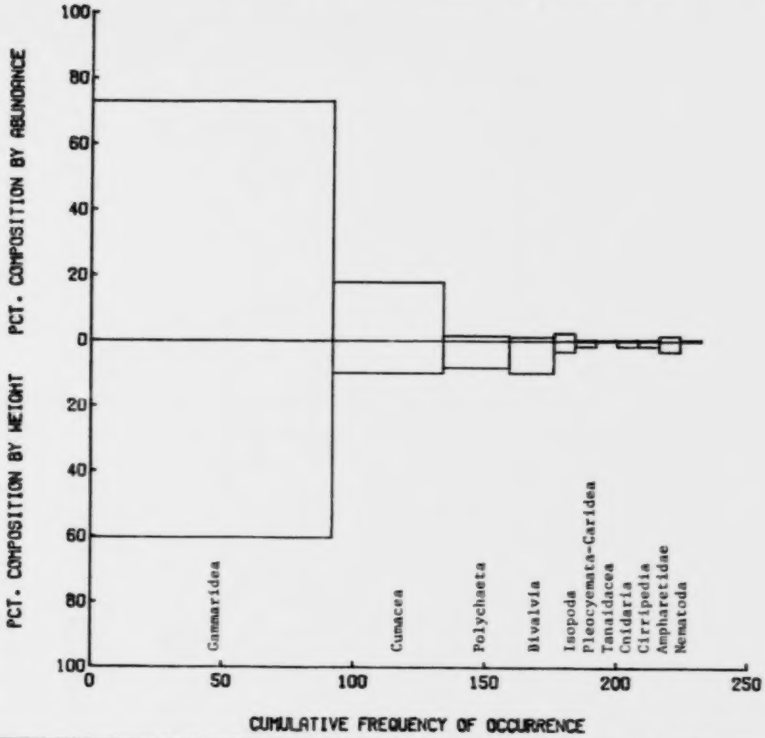
    CUMACEA                       67.00  49.80  33.07  5552.3     62.00
    GAMMARIDEA                    63.00  27.81   7.98  2254.8     25.20
    POLYCHAETA                    55.00   8.74   7.02   866.8      9.70
    TANAIDACEA                    35.00   2.40    .15    89.2      1.00
    BIVALVIA                      13.00   1.14    .66    23.4       .30
    HARPACTICOIDA                 13.00    .41    .00     5.3       .10
    COPEPODA                      11.00   4.17    .04    46.3       .50
    MYSIDACEA                      9.00   1.44   2.61    36.5       .40
    OXYRHYNCHA                     2.00    .92  37.05    75.9       .10

      PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
      COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
      (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

         PERCENT DOMINANCE INDEX          .34    .26              .46
         SHANNON-WEINER DIVERSITY        1.90   1.82             1.44
         EVENNESS INDEX                   .60    .61              .45
```

Fig. B-70. IRI prey spectrum of juvenile English sole in shallow sublittoral habitats of northern Puget Sound.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. WW BS, STATION ALL
PREDATOR 8857041301 - PAROPHRYS VETULUS
(ENGLISH SOLE) ADJUSTED SAMPLE SIZE = 120



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	92.00	73.06	60.33	12271.9	87.70
CUMACEA	42.00	17.96	9.92	1171.0	8.40
POLYCHAE	25.00	1.63	8.26	247.2	1.80
BIVALVIA	17.00	1.22	9.92	189.4	1.40
ISOPODA	8.00	2.45	3.31	46.1	.30
PLEOCYEMATA-CARIDEA	8.00	.41	1.65	16.5	.10
TANAIDACEA	8.00	.41	.00	3.3	.00
CNIDARIA	8.00	.41	1.65	2.1	.00
CIRRIPEDIA	8.00	.41	1.65	2.1	.00
AMPHARETIDAE	8.00	1.63	3.31	39.5	.30
NEMATODA	8.00	.41	.00	3.3	.00

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

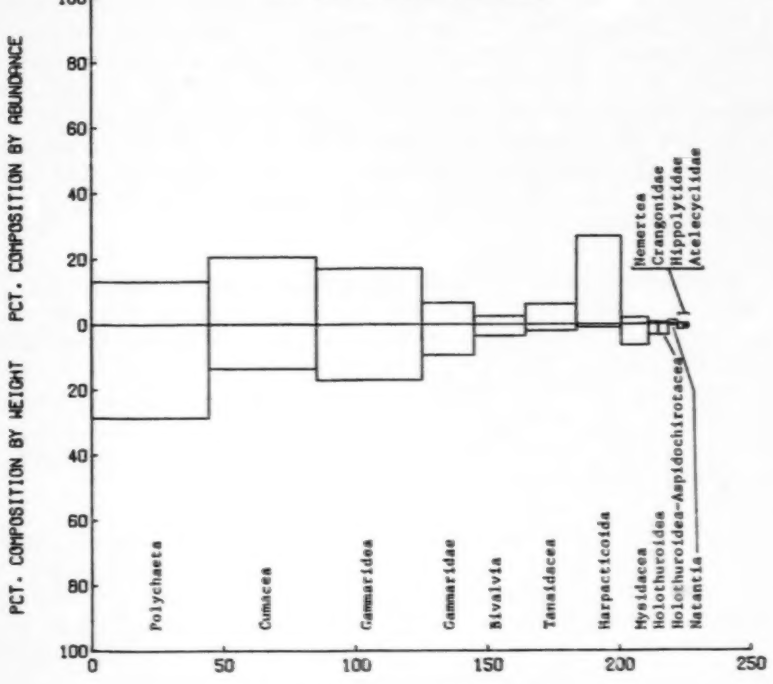
	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.57	.39	.78
SHANNON-WEINER DIVERSITY	1.34	2.02	.72
EVENNESS INDEX	.39	.64	.26

Fig. B-71. IRI prey spectrum of juvenile English sole in shallow sublittoral habitats along eastern shoreline of northern Puget Sound.

Reproduced from best available copy.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78. STATION ALSTA

8857041301 - PAROPHRYS VETULUS
ENGLISH SOLE
ADJUSTED SAMPLE SIZE = 366



CUMULATIVE FREQUENCY OF OCCURRENCE

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
POLYCHAETA	44.54	13.08	28.68	1860.0	32.02
CUMACEA	40.71	20.53	13.51	1385.7	23.86
GAMMARIDEA	39.89	17.08	17.03	1360.6	23.42
GAMMARIDAE	19.95	6.46	9.44	317.1	5.46
BIVALVIA	19.40	2.45	3.60	117.4	2.02
TANAIDACEA	19.40	6.10	2.05	158.2	2.72
HARPACTICOIDA	16.94	26.79	1.00	470.8	8.10
MYSIDACEA	10.38	1.99	6.46	87.7	1.51
HOLOTHUROIDEA	3.83	.59	3.31	14.9	.26
HOLOTHUROIDEA ASPIDOCHIROTACEA	3.83	.47	3.37	14.7	.25
NATANTIA	3.28	1.09	.38	4.8	.08
NEMERTEA	2.46	.13	1.57	4.2	.07
CRANGONIDAE	1.09	.03	1.39	1.5	.03
HIPPOLYTIDAE	.27	.02	1.44	.4	.01
ATELECYCLIDAE	.27	.02	1.07	.3	.01

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.17	.15	.23
SHANNON-WEINER DIVERSITY	2.99	3.42	2.47
EVENNESS INDEX	.54	.61	.44

Fig. B-72. IRI prey spectrum of juvenile English sole in shallow sublittoral habitats along Strait of Juan de Fuca.

Starry Flounder

Adult starry flounder were frequently captured in beach seine collections in northern Puget Sound (Eagle Cove and South Beach) from July through November though never in large numbers. The most frequently consumed prey organisms were flabelliferan isopods which accounted for 58.9 percent of the total IRI. Fish (18.2 percent) were second in importance, followed by gammarid amphipods (8.2 percent), epicaridan isopods (4.5 percent), polychaetes (3.7 percent), gastropods (3.3 percent), and turbellarians (1.2 percent). The amphipods were primarily *Atylus* sp. but also *Eusiroides* sp. and *Amphithoe* so. All prey, except perhaps the fish, were epibenthic or benthic organisms.

Juvenile starry flounder also appeared in beach seine collections along the eastern shoreline, principally in sand/eelgrass (Birch Bay, East Guemes Island) and mud/eelgrass (Padilla Bay, Drayton Harbor) habitats in August through December. While isopods (primarily valviferan) were still important (30.2 percent of total IRI) in these samples, gammarid amphipods (33.4 percent), barnacles (16.7 percent), and oligochaetes (11.8 percent) were much more prevalent in the diets of starry flounders on the eastern shore than at San Juan Island (Fig. B-73).

Although not as numerous as English sole, starry flounder occurred along the Strait of Juan de Fuca in all but the Dungeness Spit beach seine collections; juveniles and adults occurred in approximately equal proportions. The overall prey spectrum (Fig. B-74) was quite similar to that of the rock sole (Fig. B-69); polychaete annelids, gammarid amphipods, and tanaids supplied the greatest proportions of the total IRI.

C-O Sole

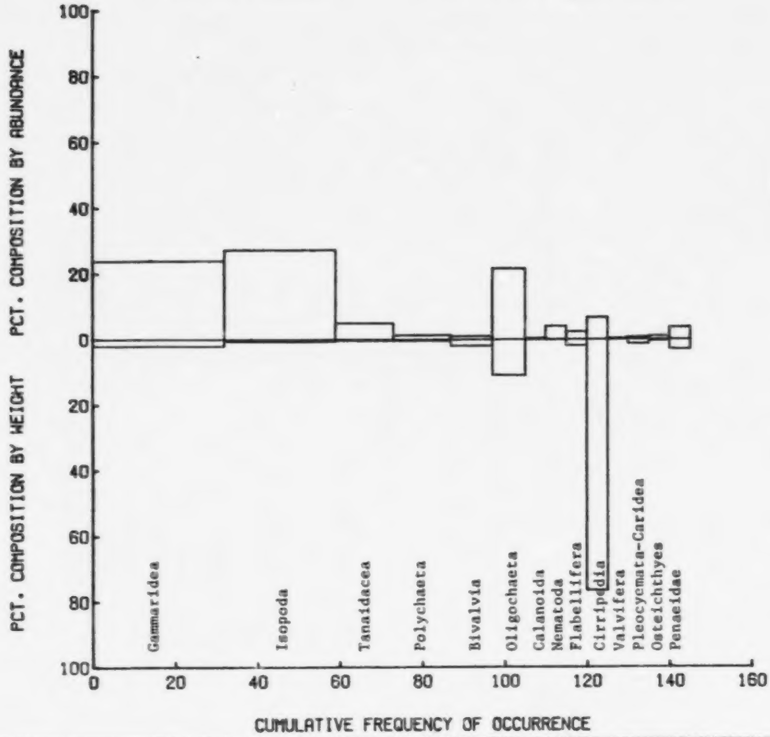
C-O sole were caught during beach seine collections at South Beach and Deadman Bay in northern Puget Sound. Their principal prey items were flabelliferan isopods (45.8 percent of total IRI), fish (21.4 percent), polychaetes (14.3 percent), amphipods (9.2 percent), and turbellarians (4.4 percent). One C-O sole from a beach seine collection at southern Guemes Island in July 1974 had 12 bivalves (98.0 percent of total biomass) and 10 pieces of algae (Rhodophyta) in its stomach.

C-O sole collected from the Strait of Juan de Fuca almost exclusively originated from the protected, sand-eelgrass habitat at Beckett Point. Polychaete annelids, with over 80% of the total IRI, were the most important prey taxa and bivalves contributed almost 13% (Fig. B-75).

Sand Sole

In sand sole from the eastern shoreline of northern Puget Sound (Birch Bay), gammarid amphipods were the most important prey taxa, with 82.1 percent of the total IRI (Fig. B-76). Polychaetes supplied 8.3 percent and epibenthic organisms--tanaids (3.8 percent), cumaceans (3.4 percent), and valviferan isopods (1.3 percent)--accounted for the remaining proportion.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. WW BS. STATION ALL
PREDATOR 8857041401 - PLATICHTHYS STELLATUS
(STARRY FLOUNDER) ADJUSTED SAMPLE SIZE = 22

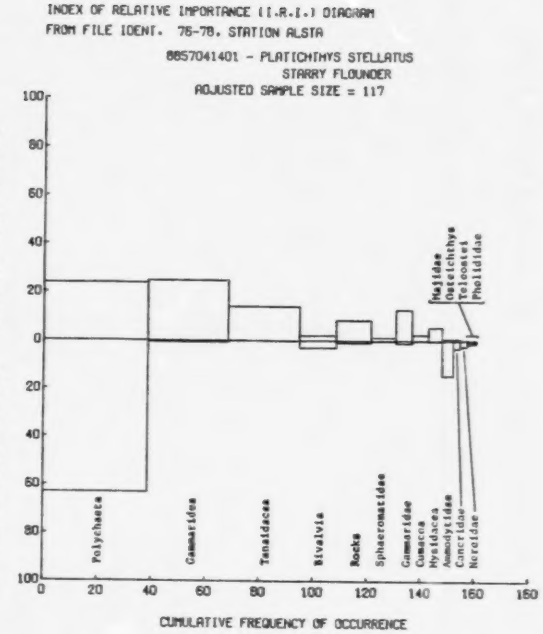


PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	32.00	23.92	2.07	831.7	33.00
ISOPODA	27.00	27.24	.61	752.0	29.90
TANAIDACEA	14.00	4.98	.31	74.1	2.90
POLYCHAETA	14.00	1.33	.38	23.9	1.00
BIVALVIA	10.00	.99	1.99	29.8	1.20
OLIGOCHAETA	8.00	21.59	11.03	293.6	11.70
CALANOIDA	5.00	.33	.00	1.6	.00
NEMATODA	5.00	3.99	.04	20.1	.80
FLABELLIFERA	5.00	2.33	1.91	21.2	.80
CIRRIPEDIA	5.00	6.64	76.60	416.2	16.50
VALVIFERA	5.00	.33	.00	1.6	.00
PLEOCYEMATA-CARIDEA	5.00	.66	1.38	10.2	.40
OSTEICHTHYES	5.00	1.00	.38	6.9	.30
PENAEIDAE	5.00	3.65	3.06	33.5	1.30

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.19	.60	.24
SHANNON-WEINER DIVERSITY	2.76	1.36	2.38
EVENNESS INDEX	.73	.38	.66

Fig. B-73. IRI prey spectrum of starry flounder in shallow sublittoral habitats along eastern shoreline of northern Puget Sound.



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TOMACH ANALYSIS                                                    PAGE  3
***************
 SPECIES: 8857041401-PLATICHTHYS STELLATUS              STARRY FLOUNDER

              INDEX OF RELATIVE IMPORTANCE (I.R.I.) TABLE
              USING FILEID=  76-78. STATION= ALSTA FOR PLOT
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                                  FREQ   NUM.   GRAV.   PREY    PERCENT
          PREY ITEM               OCCUR  COMP.  COMP.   I.R.I.  TOTAL IRI
  -------------------------       -----  -----  -----   ------  ---------

  POLYCHAETA                      38.46  23.81  63.16   3344.9    68.06
  GAMMARIDEA                      29.91  24.82    .70    763.3    15.53
  TANAIDACEA                      26.50  13.99    .16    374.8     7.63
  BIVALVIA                        13.68   2.14   2.97     69.9     1.42
  ROCKS                           12.92   8.46    .90    120.0     2.44
  SPHAEROMATIDAE                   9.40   1.26    .20     13.5      .27
  GAMMARIDAE                       5.98  12.71   1.13     82.8     1.68
  CUMACEA                          5.98   2.48    .03     15.0      .31
  MYSIDACEA                        5.13   5.49    .19     29.1      .59
  AMMODYTIDAE                      4.27    .68  14.54     65.0     1.32
  CANCRIDAE                        2.56    .53   3.29      9.8      .20
  NEREIDAE                         2.56    .26   2.45      7.0      .14
  MAJIDAE                           .85    .11   1.54      1.4      .03
  OSTEICHTHYS                       .85    .06   1.56      1.4      .03
  TELEOSTEI                         .85    .04   1.16      1.0      .02
  PHOLIDIDAE                        .85    .04   1.35      1.2      .02


  PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
   COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
   (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

       PERCENT DOMINANCE INDEX           .17    .42                 .49
       SHANNON-WEINER DIVERSITY         3.06   2.21                1.65
       EVENNESS INDEX                    .56    .41                 .30
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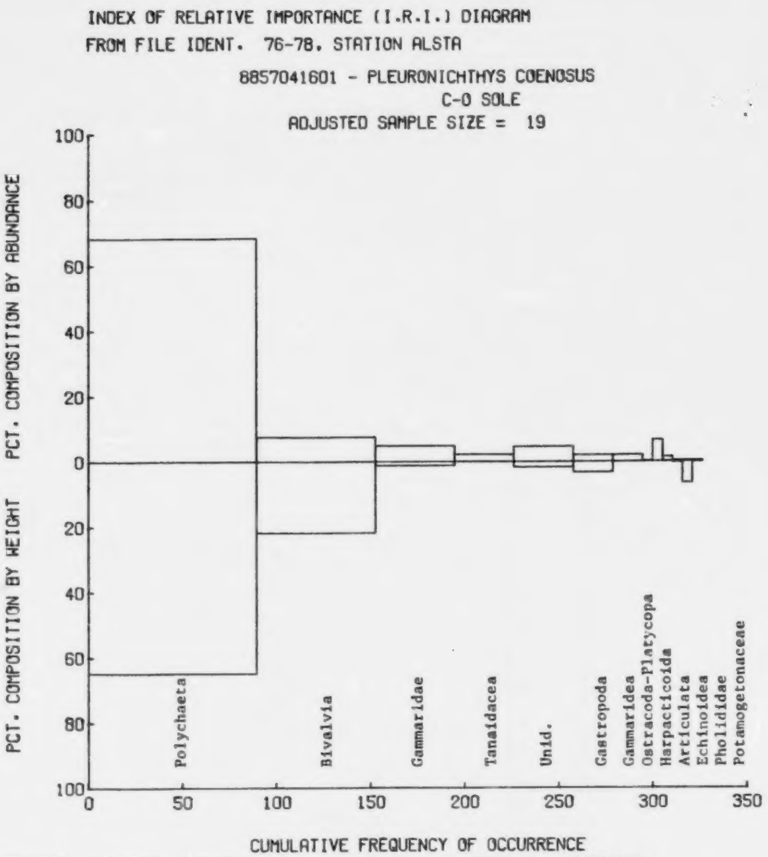
Fig. B-74. IRI prey spectrum of starry flounder in shallow sublittoral habitats along Strait of Juan de Fuca.



INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78. STATION ALSTA
8857041601 - PLEURONICHTHYS COENOSUS
C-O SOLE
ADJUSTED SAMPLE SIZE = 19

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                               FREQ   NUM.   GRAV.   PREY    PERCENT
      PREY ITEM                OCCUR  COMP.  COMP.   I.R.I.  TOTAL IRI
----------------------------   -----  -----  -----   ------  ---------

POLYCHAETA                     89.47  68.27  64.88  11913.3    82.09
BIVALVIA                       63.16   7.44  21.84   1849.2    12.74
GAMMARIDAE                     42.11   4.81   1.26    255.8     1.76
TANAIDACEA                     31.58   2.19    .01     69.6      .48
UNIDENTIFIED                   31.58   4.60   1.73    199.9     1.38
GASTROPODA                     21.05   1.97   3.30    110.9      .76
GAMMARIDEA                     15.79   1.97    .07     32.2      .22
OSTRACODA PLATYCOPA             5.26    .22    .00      1.2      .01
HARPACTICOIDA                   5.26   6.56    .01     34.6      .24
ARTICULATA                      5.26   1.31    .01      6.9      .05
ECHINOIDEA                      5.26    .22    .18      2.1      .01
PHOLIDIDAE                      5.26    .22   6.59     35.9      .25
POTAMOGETONACEAE                5.26    .22    .12      1.8      .01

  PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC
  COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT
  (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

     PERCENT DOMINANCE INDEX           .48    .47                   .69
     SHANNON-WEINER DIVERSITY         1.83   1.53                   .96
     EVENNESS INDEX                    .49    .41                   .26
```

Fig. B-75. IRI prey spectrum of C-O sole in shallow sublittoral habitats along Strait of Juan de Fuca.

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
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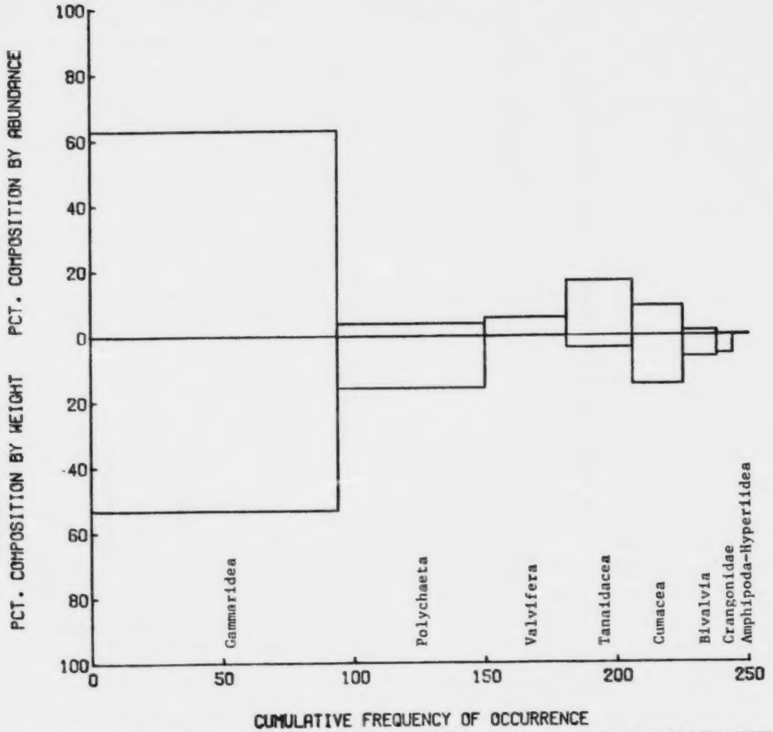
(SAND SOLE) ADJUSTED SAMPLE SIZE = 16



PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
GAMMARIDEA	94.00	62.90	53.27	10920.0	82.10
POLYCHAETA	56.00	3.77	15.89	1111.0	8.40
VALVIFERA	31.00	5.51	.00	170.8	1.30
TANAIDACEA	25.00	16.81	3.74	513.7	3.90
CUMACEA	19.00	8.99	14.95	454.9	3.40
BIVALVIA	13.00	1.45	6.54	103.9	.80
CRANGONIDAE	6.00	.29	5.61	35.4	.30
AMPHIPODA-HYPERIIDEA	6.00	.29	.00	1.7	.00

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

	NUM. COMP.	GRAV. COMP.	PERCENT TOTAL IRI
PERCENT DOMINANCE INDEX	.44	.34	.68
SHANNON-WEINER DIVERSITY	1.71	1.98	1.04
EVENNESS INDEX	.57	.77	.37

Fig. B-76. IRI prey spectrum of sand sole in shallow sublittoral habitats along eastern shoreline of northern Puget Sound.

In the Strait of Juan de Fuca sand sole were almost as abundant as English sole but originated primarily from the four western beach seine sites. The overall prey spectrum (Fig. B-77) showed a radical difference from northern Puget Sound and from the other flatfish by the predominance of epibenthic mysids (primarily *Neomysis awatschensis* but also including *N. rayi* and *Archaeomysis grebnitzki*, accounting for 88.9% of the total IRI) and the absence of polychaetes. Other epibenthic crustaceans, such as gammarid amphipods, cumaceans, and shrimp (including *Crangon stylirostris* and *Pandalus danae*), were the secondary prey. Fish (including juvenile Pacific herring, Pacific sand lance, tidepool snailfish, *Liparis florae*, and sand sole, *Psettichthys melanostictus*) accounted for 31.5% of the total prey biomass but were not common or abundant enough to provide a high (1.5%) proportion of the total IRI.

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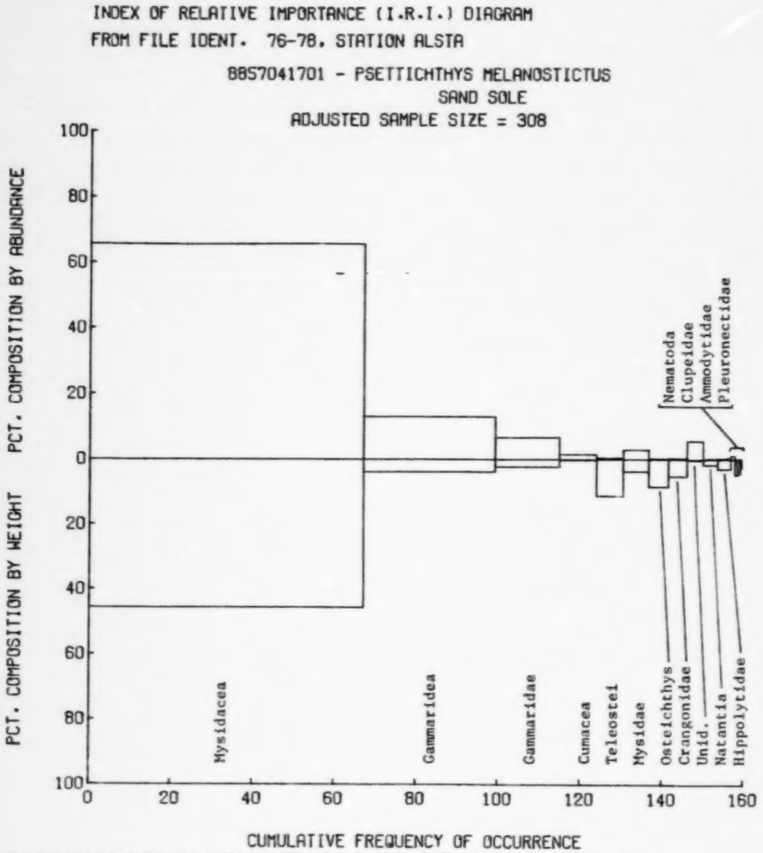

INDEX OF RELATIVE IMPORTANCE (I.R.I.) DIAGRAM
FROM FILE IDENT. 76-78, STATION ALSTA
8857041701 - PSETTICHTHYS MELANOSTICTUS
SAND SOLE
ADJUSTED SAMPLE SIZE = 308

PREY ITEM	FREQ OCCUR	NUM. COMP.	GRAV. COMP.	PREY I.R.I.	PERCENT TOTAL IRI
MYSIDACEA	67.21	65.61	45.68	7479.5	88.85
GAMMARIDEA	32.14	13.01	3.91	543.9	6.46
GAMMARIDAE	15.58	6.66	2.34	140.3	1.67
CUMACEA	9.09	1.54	.18	15.7	.19
TELEOSTEI	5.49	.50	11.19	76.0	.90
MYSIDAE	6.17	2.95	3.76	41.4	.49
OSTEICHTHYS	4.87	.27	8.40	42.2	.50
CRANGONIDAE	4.55	.41	5.21	25.6	.30
UNIDENTIFIED	3.90	5.60	.27	22.9	.27
NATANTIA	3.57	.22	1.73	7.0	.08
HIPPOLYTIDAE	3.25	.36	2.99	10.9	.13
NEMATODA	.97	1.04	.01	1.0	.01
CLUPEIDAE	.65	.03	4.79	3.1	.04
AMMODYTIDAE	.65	.06	4.38	2.9	.03
PLEURONECTIDAE	.32	.01	2.65	.9	.01

PREY TAXA WITH FREQ. OCCUR. LESS THAN 5 AND NUMERICAL AND GRAVIMETRIC COMPOSITION BOTH LESS THAN 1 ARE EXCLUDED FROM THE TABLE AND PLOT (BUT NOT FROM CALCULATION OF DIVERSITY INDICES)

PERCENT DOMINANCE INDEX		.46	.24		.79
SHANNON-WEINER DIVERSITY		1.90	2.91		.75
EVENNESS INDEX		.37	.56		.14

Fig. B-77. IRI prey spectrum of sand sole in shallow sublittoral habitats along Strait of Juan de Fuca.

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APPENDIX C: SEA BIRDS AND SHORE BIRDS

Eighty-one species of marine or estuarine-associated birds are reported or could be safely assumed to consistently occur in north Puget Sound and the Strait of Juan de Fuca (Jewett, et al., 1953; Robbins, et al., 1966; Alcorn 1971; Salo 1975; Manuwal 1977). Ten species occur in abundance and represent sizable breeding or wintering populations; an additional 54 species could be considered common, many of which are seasonal migrants and residents. The remaining species are either not commonly encountered--e.g., they migrate through the region offshore--or numerically unimportant (Table C-1).

The following species accounts discuss food habits and feeding behavior of all species for which such data could be found. For many species, especially the shore birds, there were few, or very unspecific, data available for this region. In those cases, information for that species occurring outside the Pacific Northwest was utilized, or in the instances of no such data, the diet was inferred from congeneric species. Several review references, notably Jewett, et al. (1953), Eaton (1975), and Salo (1975), were extremely useful in locating data on the general food habits of the less-known birds.

The functional feeding groups of the 55 abundant and common marine and shore birds associated with north Puget Sound and Strait of Juan de Fuca habitats are summarized in Table C-2. Of these species, 19 (35%) utilize fishes as their principal prey resources, as either obligate or facultative piscivores; 18 (33%) feed mainly on benthic invertebrates in the littoral or shallow sublittoral zones; 7 (13%) are omnivorous, eating both plants and invertebrates; 5 (9%) are planktivorous; 4 (7%) are herbivorous; and 2 (3%) are either parasitic, or like the bald eagle, facultative avivores preying on both sea birds and fish.

Sixteen (29%) of the bird species feed in the shallow sublittoral zone, which includes much of the sand to cobble shoreline and embayments in this region; 14 (25%) feed in the salt marsh and mudflat environments characteristic of large estuaries or contained embayments; 11 (20%) feed in neritic waters; 4 (7%) obtain their prey on relatively exposed sand-gravel beaches; 3 (5%) utilize the fauna of the rocky littoral environment or the adjacent kelp bed fauna; and 4 (7%) gulls have to be essentially universal to almost all of these habitats.

Species Accounts

Arctic Loon

Arctic loons occur in north Puget Sound between October and May, primarily as migrants and winter residents (Jewett, et al., 1953; Alcorn 1971;

Table C-1. Relative abundance of marine and shore birds known to the northern Puget Sound and Strait of Juan de Fuca area. A = abundant, C = common, NC = not common, R = rare; asterisk denotes seasonal occurrence.

Scientific name	Common name	Abundance
Order Gaviiformes		
Gavia arctica	Arctic loon	C*
G. immer	common loon	C
G. stellata	red-throated loon	C*
Order Podicipediformes		
Family Podicipedidae	grebes	
Aechniophorus occidentalis	western grebe	A
Podiceps auritus	horned grebe	C*
P. grisegena	red-necked grebe	C*
P. nigricollis	eared grebe	C*
Order Procellariiformes		
Family Procellariidae	fulmars	
Filmarus glacialis	fulmar	NC
Puffinns griseus	sooty shearwater	NC
Family Hydrobatidae	storm petrel	
Oceanodroma leucorhoa	Leach's petrel	NC
Order Pelecaniformes		
Family Phalacrocoracidae	cormorants	
Phalacrocorax penicillatus	Brandt's cormorant	C*
P. auritus	double-crested cormorant	C
P. pelagicus	pelagic cormorant	C
Order Anseriformes		
Family Anatidae	waterfowl	
Branta canadensis	Canada goose	C*
B. nigricans	black brant	A*
Anser albifrons	white-fronted goose	NC*
Chen hyperborea	snow goose	C*
Anas platyrhynchos	mallard	A*
A. aeuta	pintail	C*
A. clypeata	northern shoveler	C*
A. carolinensis	green-winged teal	NC*
Mareca americana	American widgeon	C*
Aythya valisineria	canvasback	NC*
A. marila	greater scaup	NC*
A. affinis	lesser scaup	A*

Table C-1. Relative abundance of marine and shore birds known to the northern Puget Sound and Strait of Juan de Fuca area. A = abundant, C = common, NC = not common, R = rare; asterisk denotes seasonal occurrence, continued.

Scientific name	Common name	Abundance
Bucephala clangula	common goldeneye	C*
B. islandica	Barrow's goldeneye	C*
B. albeola	bufflehead	C*
Clangula hyemalis	oldsquaw	C*
Histrionicus histrionicus	harlequin duck	NC*
Melanitta deylandi	white-winged scoter	C*
M. perspicillata	surf scoter	A
M. nigra	black scoter	NC*
Family Anatidae	mergansers	
Mergus merganser	common merganser	C
M. sernaton	red-breasted merganser	C*
Order Falconiformes		
Family Pandionidae	ospreys	
Pandion halinetus	osprey	NC
Family Accipitridae	kites, hawks, eagles	
Aalineetus leucocephalus	bald eagle	C
Order Ciconiiformes		
Family Ardeidae	herons, bitterns	
Ardea herodias	great blue heron	C
Order Gruiformes		
Family Rallidae	rails, gallinules, coots	
Rallus limicola	Virginia rail	R
Fulica americana	American coot	C
Order Charadriiformes		
Family Haematopodidae	oystercatchers	
Haematopus bachmani	black oystercatcher	C
Family Charadriidae	plovers, surfbirds, turnstones	
Charadrius semipalmatus	semipalmated plover	NC*
Family Scolopacidae	sandpipers	
Numenius phaeopus	whimbrel	C
Actitis macularia	spotted sandpiper	A*
Heteroscelus incanum	wandering tattler	NC*
Limnodromus griseus	short-billed dowitcher	C
L. scolopaceus	long-billed dowitcher	C
Aphriza virgata	surfbird	C*

Table C-1. Relative abundance of marine and shore birds known to the northern Puget Sound and Strait of Juan de Fuca area. A = abundant, C = common, NC = not common, R = rare; asterisk denotes seasonal occurrence, continued.

Scientific name	Common name	Abundance
Arenaria interpres	ruddy turnstone	NC*
A. melanocephala	black turnstone	C*
Tringa melanoleuca	greater yellowlegs	C*
Calidris ptilocnemis	rock sandpiper	NC*
C. alpina	dunlin	C*
C. canutus	knot	C
C. minutilla	least sandpiper	C
Ereunetes mauri	western sandpiper	A
Crocethia alba	sanderling	C*
Family Phalaropodidae	phalaropes	
Phalaropus tricolor	Wilson's phalarope	NC*
Lobipes lobatus	northern phalarope	NC*
Family Stercorariidae	jaegers, skuas	
Stercorarius parasiticus	parasitic jaeger	C*
S. pomarinus	pomarine jaeger	NC*
Family Laridae	gulls	
Larus glaucescens	glaucous-winged gull	A
L. occidentalis	western gull	C*
L. nurgentatus	herring gull	C
L. californicus	California gull	C*
L. delawarensis	ring-billed gull	C*
L. canus	mew gull	C*
L. heermanni	Heermann's gull	C*
L. philadelphia	Bonaparte's gull	A
Xema sabini	Sabine's gull	NC
Rissa tridactyla	blacklegged kittiwake	C*
Sterna hirundo	common tern	C*
S. paradisnea	Arctic tern	C*
Hydroprogne caspia	Caspian tern	C*
Family Alcidae	alcids	
Uria aalge	common murre	C*
Cepphus columba	pigeon guillemot	C
Lunda cirrhata	tufted puffin	C
Cerorhinea monocerata	rhinoceros auklet	A
Ptychoramphus aleutica	Cassin's auklet	R
Synthliboramphus antiguum	ancient murrelet	C*
Brachyramphus marmoratum	marbled murrelet	C

Table C-2. Functional feeding groups and representative prey taxa of 58 marine and shore birds common to northern Puget Sound and the Strait of Juan de Fuca.

Habitat	Trophic position	Predator species	Prey taxa
Offshore neritic	Obligate piscivore	Common murre Black-legged kittiwake Common tern Rhinoceros auklet Western grebe	Northern anchovy Eulachon Pacific herring Pacific sand lance Juv. rockfish Juv. Pacific salmon Surf smelt Night smelt Walleye pollock Threespine stickleback
	Facultative piscivore	Tufted puffin Marbled murrelet Ancient murrelet	Pacific sand lance Pacific herring Surf smelt Northern anchovy Rockfish Shiner perch Juv. rockfish Sea urchins (*Strongylocentrotus* sp.) Bivalve molluscs (*Mytilus* sp.) Euphausiids
	Obligate planktivore	Cassins auklet	Calanoid copepods (*Calanus* sp.) Hyperiid amphipods (*Parathemisto* sp.) Euphausiids

Table C-2. Functional feeding groups and representative prey taxa of 55 marine and shore birds common to northern Puget Sound and the Strait of Juan de Fuca, continued.

Habitat	Trophic position	Predator species	Prey taxa
	Facultative planktivore	Mew gull Bonaparte's gull	Euphausiids Hyperiid amphipods Pacific herring (larv.?) Pacific sand lance (larv.?)
	Parasite	Parasitic jaeger	Foods of gulls and terns
Nearshore kelp beds	Facultative avivore	Bald eagle	Gulls Pigeon guillemots Cormorants Puffins Pacific herring Pacific salmon Dolly Varden Cutthroat trout Flatfishes Sculpins Sea urchins Crabs (*Pugettia producta*)
	Obligate piscivore	Brandt's cormorant	Redtail surfperch Kelp greenling Black rockfish Cabezon Pacific sand lance
	Facultative piscivore	Heermann's gull Arctic tern	Pacific herring Pacific sand lance

Table C-2. Functional feeding groups and representative prey taxa of 55 marine and shore birds common to northern Puget Sound and the Strait of Juan de Fuca, continued.

Habitat	Trophic position	Predator species	Prey taxa
Inshore rocky littoral	Obligate benthivore	Black oystercatcher Whimbrel Black turnstone	Limpets *Collisella digitalis* *Notoacmea scutum* *Acmea mitra* Chitons (*Katharina tunicata*) Bivalve molluscs *Mytilus edulis* *M. californianus* Barnacles (*Pollicipes polymerus*) Polychaete annelids (*Nereis* sp.)
Inshore sand-gravel beaches	Obligate benthivore	Spotted sandpiper Surfbird Least sandpiper Sanderling	Polychaete annelids *Nereis* sp. *Streblospio benedicti* *Eteone longa* Amphipods *Anigogammarus conferricolus* *Corophium* sp. *Orchestoidea pugettensis* Bivalve molluscs Univalve molluscs
Nearshore shallow sublittoral	Obligate piscivore	Double-crested cormorant Red-necked grebe Common merganser	Penpoint gunnel Crescent gunnel Pacific sand lance Shiner perch Snake prickleback Staghorn sculpin Pacific herring Juv. Pacific salmon Northern anchovy

Table C-2. Functional feeding groups and representative prey taxa of 55 marine and shore birds common to northern Puget Sound and the Strait of Juan de Fuca, continued.

Habitat	Trophic position	Predator species	Prey taxa
	Facultative piscivore	Arctic loon Common loon Red-throated loon Pelagic cormorant Pigeon guillemot Red-breasted merganser Caspian tern	Crescent gunnel Pacific sand lance Penpoint gunnel Staghorn sculpin Northern clingfish Snake prickleback Pacific herring Surf smelt Black prickleback Threespine prickleback Juv. flatfish (Pleuronectidae) Snake prickleback Shrimp *Spirontocaris brevirostris* *Crago alaskensis* *Pandalus* sp. Crabs (*Hemigrapsis* sp.)
	Obligate planktivore	Eared grebe	Mysids Amphipods
	Facultative benthivore	Lesser scaup Common goldeneye Bufflehead Oldsquaw Surf scoter	Bivalve molluscs *Tapes japonica* *Ostrea lurida* *Mytilus edulis* *Mya arenaria* *Macoma* sp. Crustaceans Fish Pacific herring eggs Eelgrass (*Zostera* sp.)

Table C-2. Functional feeding groups and representative prey taxa of 55 marine and shore birds common to northern Puget Sound and the Strait of Juan de Fuca, continued.

Habitat	Trophic position	Predator species	Prey taxa
Inshore, saltmarsh and mudflats	Obligate herbivore	Canada goose Black brant Snow goose American coot	Eelgrass (*Zostera* sp.) Saltmarsh plants *Salicornia* sp. *Distichlis spicata* *Cuscuta salina* *Triglochia maritimum* *Canex lyngbyei*
	Omnivore, Facultative herbivore	Mallard Pintail Northern shoveler American widgeon	Eelgrass (*Zostera* sp.) Saltmarsh plants, seeds *Salicornia* sp. *Triglochia maritinum* *Canex lyngbyei* Amphipods (*Anisogammarus confervicolus*) Insect larvae (*Aphrosylus* sp.)
	Omnivore	Dunlin Knot Western sandpiper	Saltmarsh plants, seeds *Spergularia marina* *Triglochia maritinum* *Deschampsia cespitosa* Amphipods *Corophium* sp. *Anisogammarius confervicolus* *Orchestoidea pugettensis* *Amphitoe* sp. Polychaete annelids *Nereis* sp. *Streblospio benedicti* *Amphicteis mucronata* *Eteone longa*

Table C-2. Functional feeding groups and representative prey taxa of 55 marine and shore birds common to northern Puget Sound and the Strait of Juan de Fuca, continued.

Habitat	Trophic position	Predator species	Prey taxa
			Oligochaetes Bivalve molluscs *Macoma inconspicua* *Mya arenaria* Tanaids (*Pancolus californiensis*) Nematodes
	Obligate piscivore	Great blue heron	Staghorn sculpin Starry flounder Shiner perch Penpoint gunnel
	Obligate benthivore	Short-billed dowitcher Long-billed dowitcher	Polychaete annelids (*Nereis* sp.) Univalve molluscs Nassariidae *Littorina* sp. Bivalve molluscs (*Mytilus edulis*) Crabs Shrimp Isopods (*Exosphaeroma oregonensis*) Amphipods *Corophium spinicorne* *Echinogammarus ochotensis*
	Facultative benthivore	Greater yellowlegs	Molluscs Crustaceans Fish

Table C-2. Functional feeding groups and representative prey taxa of 55 marine and shore birds common to northern Puget Sound and the Strait of Juan de Fuca, continued.

Habitat	Trophic position	Predator species	Prey taxa
Universal	Facultative benthivore	Glaucous-winged gull	Chitons
		Western gull	Starfish
		California gull	Sea cucumbers
		Ring-billed gull	Sea urchins (*Strongylocentrotus* sp.)
			Crabs
			Cancer sp.
			Hemigrapsus sp.
			Bivalve molluscs
			Mytilus edulis
			Clinocardium nuttalli
			Polychaete annelids (*Nereis* sp.)
			Pacific herring
			Northern anchovy
			Surf smelt
			Pacific herring eggs
			Cormorant fledglings
			Murre fledglings

Salo 1975). They are quite common in the San Juan Islands, often in large aggregations (up to 1,000) during migration (Salo 1975; Heilbrum, et al., 1977). When on marine waters arctic loons are assumed to eat fish, crustaceans, and molluscs (Martin, et al., 1951; Salo 1975).

Common Loon

The only year-round resident loon, common loons tend to be more abundant in marine habitats during winter, though seldom in as large concentrations as arctic loons (Jewett, et al., 1953; Alcorn 1971; Salo 1975). Wintering common loons appear to feed primarily on fish (Martin, et al., 1951; Jewett, et al., 1953). Salo (1975) reported a common loon preying on small 10-13 cm flounders off Sandy Point, Whidbey Island.

Red-Throated Loon

Red-throated loons, the least common of the three loon species, are migrants and winter residents in north Puget Sound, and occur in aggregations of up to 100 birds. They appear to be fairly abundant in the San Juan Islands (Jewett, et al., 1953; Alcorn 1971; Salo 1975). Jewett, et al. (1953), and Martin, et al. (1951), reported the generalized diet of red-throated loons as including fish, crustaceans, molluscs, fish eggs, leeches, insects, and some aquatic vegetation.

Western Grebe

Overall, western grebes were the most abundant of the species observed in Manuwal's (1977) seven transect surveys in the San Juan Islands conducted from ferries between November 1973 and April 1974. They appear primarily as wintering populations, although some non-breeding birds may reside in Puget Sound through the summer (Jewett, et al., 1973; Salo 1975). Fish are the primary prey organisms of western grebes (Munro 1941a; Jewett, et al., 1953; Phillips and Carter 1957; Salo 1975). Species which have been identified as prey include Pacific herring (*Clupea harengus pallasi*), especially during spawning periods, staghorn sculpin (*Leptocottus armatus*) and other sculpins, shiner perch (*Cymatogaster aggregata*), and smelt (Osmeridae). Shrimp (*Pandalus goniurus*) were also reported as prey.

Horned Grebe

Breeding horned grebes are common migrants on Puget Sound in winter, typically from September through May, and a few non-breeding birds occur in summer (Munro 1941a; Jewett, et al., 1953; Bakus 1965; Salo 1975). In Manuwal's (1977) ferry transect surveys through the San Juan Islands, they were observed to be numerous only once, in January 1974. Fish (Pacific sand lance, *Ammodytes hexapterus*, Pacific herring, and staghorn sculpin) and small shrimp (*Spirontocaris brevirostris*, *Crago alaskensis*, and *Pandalus* sp.) and crabs (*Hemigrapsis* sp.) appear to be most important to the horned grebe feeding on marine waters (Munro 1941a; Guiguet 1971b).

Red-Necked Grebe

Of the species of grebes frequenting Puget Sound, the red-necked grebe is probably the least abundant. It follows the same pattern of occurrence, however, residing as a winter migrant between November and May (Munro 1971a; Jewett, et al., 1958; Salo 1975). It occurred in abundance during two of Manuwal's (1977) San Juan Island ferry transect surveys, in January and April 1974. Spawning Pacific herring, Pacific sand lance, pilchard (*Sardinops caerulea?*), threespine stickleback (*Gasterosteus aculeatus*), blenny (Pholidae and Stichaeidae?), and sculpin (Cottidae) have been reported as food organisms (Munro 1941a; Guiguet 1971b; Salo 1975).

Eared Grebe

Like the other grebes, eared grebes are mainly winter migrants, and are similar to horned grebes in distribution and abundance (Jewett, et al., 1953; Salo 1975; Heilbrum, et al., 1977). They did not appear in significant numbers, however, during Manuwal's (1977) ferry transect surveys through the San Juan archipelago. Unlike the other grebes, eared grebes feeding in marine habitats eat planktonic crustaceans--mysids and amphipods (Munro 1941a).

Fulmar

Jewett, et al. (1953), and Sanger (1965, 1970) provide indications and data that fulmars are generally abundant in nearshore areas along the Washington coast in fall (September-October), although it appears that their incidence inside the Strait of Juan de Fuca is rare. Martin (1942) suggested that fulmars were apparently more abundant off the northwest coast of Vancouver Island in winter.

Sanger and Baird (1977) listed fish (70% frequency of occurrence), squid (70%), and crustaceans (20%) as the principal prey of fulmars collected in Alaskan waters between 1969 and 1976. Fulmars collected in April from along the Bering Sea icepack had consumed only squid.

Sooty Shearwater

Sooty shearwaters appear in the region's offshore waters between March and October (Martin 1942) but seldom occur in nearshore waters (Dr. Dave Manuwal, Univ. Washington, pers. comm.). Anchovies (Engraulidae) contributed 80% of the diet by volume of sooty shearwaters off Oregon, and other fishes and squid provided the difference, as reported by Wiens and Scott (1975) who calculated their total annual energy demand to equal 1.653 k cal m^{-2}. Feeding off northwest Vancouver Island was observed to include Pacific sand lance and euphausiids (Martin 1942). Sanger and Baird's (1977) account of the major food items of sooty shearwaters collected in Alaskan waters between 1967 and 1976 indicated that fish occurred in 61% and squid in 46% of the stomachs examined.

Leach's Petrel

Martin (1942) described the Leach's petrel as the second most frequently seen bird in offshore areas from February through June, though never in high abundance. Sanger (1970), however, reported this species as the least abundant and least frequently seen during his surveys. According to Manuwal's (1977) surveys, 3,655 pairs of Leach's petrels were breeding on the outer coast of Washington, centered at Carroll Island; their occurrence inside the Strait of Juan de Fuca is rare, however. In Wiens and Scott's (1975) energy modeling study, hydrozoa and euphausiids were listed as the principal dietary components by percent volume for Leach's petrel. The model output predicted a total annual energy demand of 0.106 k cal m^{-2} for this species, the lowest estimate of the four species modeled.

Brandt's Cormorant

The majority of Brandt's cormorants appear to migrate into the north Puget Sound region from California breeding colonies between October and April, peak abundance occurring between November and February (Wahl 1977). Breeding colonies of 20 to 50 mating pairs, however, do occur on the outer coast at Point Grenville, Grenville Arch, Willoughby Rock, and Quillayute Needles (Manuwal 1977); these birds may constitute many of those feeding in the western Strait of Juan de Fuca. The 1976 Audubon Christmas bird count (Heilbrum, et al., 1977) reported 479 sightings at Victoria, B.C., 438 at Pender Islands, B.C., 12 in the San Juan Islands, 110 at Bellingham, and 15 in the Sequim-Dungeness area.

Gabrielson and Jewett's (1940) account of Brandt's cormorant in Oregon listed "trash fish" as the primary food. Scott's (1973) data indicated that, on the basis of percentage of stomach contents volume, anchovy, rockfish (Scorpaenidae), sculpin, and other fishes contribute equally to the Brandt's cormorant diet off Oregon in summer; in winter, rockfish, sculpin, and other fishes make up the diet. Using these data, Wiens and Scott (1975) determined that the total annual energy demand for this species was 2.308 k cal m^{-2}, second highest of the four species that they modeled.

Hubbs's, et al. (1970), account of the diverse prey spectrum of Brandt's cormorants feeding in southern California indicated that they typically foraged in Macrocystis kelp beds where they captured midwater fishes (blacksmith, Chromis punctipinnis, senorita, Oxyjulis californica, white seaperch, Phanerodon atripes, kelp perch, Brachyistius frenatus, and vermillion rockfish, Sebastes miniatus). Over sand bottoms, the diving birds utilized various species of flatfish (speckled sanddab, Citharichthys stigmaeus, fantail sole, Xystreurys liolepis, and curlfin turbot, Pleuronichthys decurrens) and roughback sculpin, Chitonotus pugetensis.

Martini (1966) suggested that the fish otoliths in the pellets regurgitated by western gulls actually originated from fish captured by Brandt's cormorants. These fish included Pacific hake (Merluccius productus), Pacific sanddab (Citharichthys sordidus), pink seapearch (Zalembius rosaceus), shortbelly rockfish (Sebastes jordani), sculpin (Icelinus sp.), and blackeye goby (Coryphopterus nicholsi) which may be taken at depths of 20 to 50 m or more (Hubbs, et al., 1970).

Sculpin (including cabezon, Scorpaenichthys marmoratus), juvenile rockfish, and greenling (Hexagrammidae) were the principal prey taxa consumed by

Brandt's cormorants off Oregon, except in mixed-species flocks when they fed on northern anchovy and "smelt" (Scott 1973); surfperches (Embiotocidae) were also observed in their beaks.

These data would tend to indicate that Brandt's cormorants feeding in north Puget Sound and the Strait of Juan de Fuca would also prey upon rocky/kelp bed fishes, which probably would include redtail surfperch (Amphistichus rhodoterus), kelp greenling (Hexagrammos decagrammus), white-spotted greenling (H. stelleri), several rockfish species, Pacific herring, and Pacific sand lance.

Double-Crested Cormorant

Manuwal (1977) estimated 390 nesting pairs on Washington's outer coast and 64 pairs in the San Juan Islands and the Strait of Juan de Fuca; the most numerous populations were located at Bird Rocks and Viti Rocks.

Robertson's (1974) report of food organisms regurgitated by double-crested cormorant chicks in British Columbia included 11 fishes of which gunnels (Apodichthys flavidus and Pholis laeta) were the most important (46.6% total prey abundance, 51.6% total prey weight), followed by Pacific sand lance (20.5%, 4.6%), shiner perch (15.5%, 20.5%), snake prickleback (Lumpenus sagitta, 11.5%, 10.2%), staghorn sculpin (2.7%, 5.9%), Pacific herring (1.4%, 2.7%), threespine stickleback (0.4%, 0.1%), juvenile salmon (Oncorhynchus sp., 0.2%, 0.9%), and northern anchovy (Engraulis mordax, 0.2%, 0.1%).

Unidentified crustaceans occurred in the one stomach sample listed by Sanger and Baird (1977). Scattergood's (1950) analysis of the contents from 35 stomachs collected in Maine included demersal fishes, primarily cunner (Tautogolabrus adspersus, 35.2% of total abundance of identifiable prey), shorthorn sculpin (Myoxocephalus scorpius) and longhorn sculpin (M. octodecimospinosus, 11.1% each), redfish (Sebastes marinus, 9.3%), Atlantic herring (Clupea harengus, 7.4%), winter flounder (Pseudopleuronectes americanus, 7.4%), rock gunnel (Pholis gunnellus, 7.4%), and alewife (Alosa pseudoharengus, 5.6%). Rock gunnel, winter flounder, cunner, and pollock (Pollachius virens) were the predominant fish regurgitated by chicks at the White Islands, Maine, rookery in early July, whereas in early August silversides (Meniclia notata) suddenly became predominant, followed by cunner, redfish, and rock gunnel.

Pelagic Cormorant

Pelagic cormorants are the most abundant of the nesting cormorants in the region. Manuwal (1977) listed 995 pairs in the population breeding along the outer coast and 395 pairs in the inland waters of the San Juan Islands and the Strait of Juan de Fuca. Included in the latter estimate are large colonies at Protection Island, Viti Rocks, Williamson Rocks, Bare Island, and Colville Island.

Pelagic cormorants' prey reported by Robertson (1974) included shrimp (19.4% prey abundance, 6.8% prey weight), and six species of fish: Crescent gunnel (Pholis laeta, 34.9%, 37.1%), Pacific sand lance (31.1%, 18.9%), penpoint gunnel (Apodichthys flavidus, 4.9%, 11.1%), staghorn sculpin (2.9%, 13.2%), northern clingfish (Gobiesox maeandricus, 2.9%, 5.6%), and snake prickleback (3.9%, 7.3%). It was also suggested that prey size was larger for pelagic cormorants than for double-crested cormorants.

Sculpins (Myoxocephalus sp.) were the only identifiable prey organisms taken by pelagic cormorants collected off Yaquina Head, Oregon, although these birds were also observed eating northern anchovy and "smelt" while feeding in large mixed-species flocks, and benthic crustaceans while feeding singly. Palmer (1962) listed demersal fishes (sculpin, greenling, pholids, poacher, Agonidae, and flatfish) and midwater fishes (Pacific herring and Pacific tomcod, Microgadus proximus) as the principal food organisms found in 31 stomachs collected in Alaska.

Canada Goose

Canada geese are both winter migrants and residents along the Washington coast, specifically during March through April and September to October. Although migrating flocks are composed of thousands of birds, wintering flocks are small, less than 100 individuals (Salo 1975). The 1976 Audubon Christmas bird count recorded as many as 515 Canada geese at Vancouver, B.C., 87 at Victoria, B.C., 54 at Nanaimo, B.C., and a few individuals at Sequim-Dungeness, Bellingham, and Everett, Washington (Heilbrum, et al., 1977). Martin, et al. (1951), cites the diet of wintering Canada geese in this region to include primarily reeds and the vegetative parts of barley, bulrush, and hardstem, and secondarily wheat, wild barley, and bromegrass. When Canada geese frequent marine shoreline habitats, however, eelgrasses (Zostera sp.) and saltmarsh plants (e.g., Salicornia sp., Distichlis spicata, Cuscuta salina, and Triglochin maritimum) may also enter their diet.

Black Brant

Black brant frequent the north Puget Sound region throughout the winter and spring, both as migrants and local winter residents, but they appear to be most abundant in March and April (Jewett, et al., 1953; Einarsen 1965; Salo 1975). The principal wintering sites include Padilla Bay, Samish Bay, Discovery Bay, and Sequim Bay. In April, as many as 18,000 birds have been recorded in Samish Bay, 55,000 in Padilla Bay, and 6,000 in Discovery Bay (Salo 1975; D. Moriarity and S. Oliver, Graysmarsh Wildl. Ref., pers. comm.; R.R. Parker, Wash. Dept. Game, unpubl. data). The 1976 Audubon Christmas bird count (Heilbrum, et al., 1977) included black brant sightings all over the north Puget Sound and Strait of Juan de Fuca region but in abundance only at Sequim-Dungeness. Eelgrass is the main component of the black brant's diet, augmented slightly by ulvoid algae (Einarsen 1955; Salo 1975).

White-Fronted Goose

White-fronted geese occur as migrants during the fall migration, especially in September, along the northern Olympic Peninsula in areas such as Dungeness Bay (Salo 1975). The only diet information is from the California wintering grounds where rice, vegetative parts and seeds of grasses, sedges, and wild millet, and barley were the most important foods (Martin, et al., 1951). Hence, they resemble Canada geese in their foraging and may utilize similar food sources--e.g., saltmarsh plants and eelgrasses--when feeding in estuarine habitats of this region.

Snow Goose

Like black brant, snow geese frequent the estuaries of northern Puget Sound as migrants and as local winter residents. Thus, their peak abundance occurs twice, in November and again in April (Jeffrey 1950; Jewett, et al., 1953; Alcorn 1971; Salo 1975). Contrary to the brant distribution, snow geese tend to congregate on the east side of Puget Sound, especially in Padilla Bay, Skagit Bay, and Port Susan, reaching maximum densities of 27,000 to 30,000 geese. They are reported to maintain local movements between these areas and the Fraser River delta, British Columbia (D. Manuwal, pers. comm.). Marsh plants, especially the roots and bulbs, are their principal food items when foraging in the estuary (Jeffrey 1950; Jewett, et al., 1953; Salo 1975).

Mallard

The most common of the game ducks taken recreationally in Washington, the mallard occurs mostly in freshwater habitats, but also frequents estuarine habitats, principally between November and April (Munro 1943; Jewett, et al., 1953; Alcorn 1971). The largest concentrations in north Puget Sound appear to be at Dungeness Bay (4,000-5,000 individuals), and the region encompassing Padilla Bay, Samish Bay, Skagit Bay, and Port Susan (19,500-44,000) (Salo 1975). Mallards collected from Grays Harbor on Washington's outer coast were feeding mainly on seeds of saltmarsh plants (including *Triglochin maritimum*) and incidentally on polychaete annelid worms (Smith and Mudd 1976).

Pintail

Pintails occur concurrently with American widgeons, principally in the upper tideflat regions of estuaries, as a fall and spring migrant, and probably do not represent a significant breeding population (Munro 1944; Jewett, et al., 1953; Alcorn 1971; Salo 1975). Dungeness Bay and the eastern shore between Port Susan and Boundary Bay tend to exhibit the highest concentrations of pintails (Salo 1975). Skagit Bay undoubtedly has the greatest numbers, up to 52,300 birds in October. Padilla Bay is also an important feeding area, with 13,000 to 15,000 birds in October-November (R.C. Parker, Washington Dept. Game, unpub. data). Smith and Mudd (1976) provided an indication of a diverse diet spectrum for pintails foraging in estuarine habitats at Grays Harbor, including eelgrass, seeds of the saltmarsh grasses *Carex lyngbyei* and *Triglochia maritimum*, amphipods (*Anisogammarus confervicolus*), and insect larvae (*Aphrosylus* sp.).

Northern Shoveler

Northern shovelers occur in flocks of 20 to 500 birds on sheltered estuaries and embayments between September and May (Kortright 1942; Jewett, et al., 1953; Salo 1975). They were sighted throughout the region during the 1976 Audubon Christmas bird count (Heilbrum, et al., 1977) but Victoria, B.C. (98 birds), and Bellingham, Washington (58 birds), had the greatest counts. Kortright (1942), Martin, et al. (1951), and Salo (1975) described the diet of northern shoveler as 65% plant matter--pondweed, sedge, and grass seeds--and 34% invertebrates, 19% of which were gastropod molluscs.

Green-Winged Teal

A common game bird in Washington's freshwater habitats, green-winged teal are also common in the upper estuarine habitats of the State. They are particularly abundant in the mud/eelgrass estuarine habitats along the eastern shoreline of Puget Sound, including Skagit Bay (max. of approximately 25,000 in October), Port Susan (max. of 13,700 in December), Padilla Bay (max. of 2,500 in November), and Samish Bay (max. of 5,100 in October) (R.C. Parker, Washington Dept. Game, unpub. data). Smith and Mudd (1976) listed invertebrates--amphipods (*Anisogammarus confervicolus*) and insect larvae (including *Sanderia* sp. and *Manayunkia* sp.)--as the major prey items of green-winged teal collected from mudflat habitats in upper Grays Harbor.

American Widgeon

American widgeons utilize the upper tideflat habitats of most of the major estuaries of coastal Washington and Puget Sound in winter. At that time (October to April) they usually are the most common duck on the region's marine waters (Salo 1975). Port Susan, Skagit Bay, Samish Bay, and Padilla Bay tend to support the largest concentrations, peak abundances of 32,000 to 39,000 occurring in October-November (R.C. Parker, Wn. Dept. Game, unpub. data). October-November was also the period of maximum abundance (3,500) observed at Sequim Bay, although counts usually stayed above 1,000 until after March (D. Moriarity and S. Oliver, Graysmarsh Wildlife Refuge, pers. comm.). The 1976 Audubon Christmas bird count (Heilbrum, et al., 1977) reported the greatest number of sightings in north Puget Sound at Victoria (8,201) and Vancouver (3,978) in British Columbia, and Bellingham, Washington (1,014). Widgeons examined from four sites in upper Grays Harbor had been feeding principally upon eelgrass and dwarf European eelgrass, *Z. nolti* (Smith and Mudd 1976).

Canvasback

Northeast Puget Sound bays and estuaries, including Drayton Harbor, Birch Bay, Padilla Bay, and Samish Bay, are the principal areas of canvasback concentrations, where peak abundances of up to 1,000 are reached in November (Jewett, et al., 1953; Salo 1975; R.C. Parker, Wn. Dept. Game, unpub. data). The eastern Strait of Juan de Fuca may also harbor some winter residents, especially at Dungeness Bay and Victoria, B.C. (Salo 1975; Heilbrum, et al., 1977). Jewett, et al. (1953), indicate that eelgrass and marine polychaete annelids and crustaceans constitute the canvasback's diet.

Greater Scaup

The Strait of Georgia and northern Puget Sound harbor concentrations of winter migrant and resident greater scaup from December to February (Munro 1941b; Jewett, et al., 1953; Salo 1975). Relatively high abundances were enumerated at Vancouver, B.C. (1,067), and Bellingham, Washington (1,055), during the 1976 Audubon Christmas bird count (Heilbrum, et al., 1977). Padilla Bay, where peak abundances occurred of approximately 2,700 birds, appears to harbor the highest concentrations in north Puget Sound (R.C. Parker, Wn. Dept. Game, unpub. data), although Munro (1941b) reported as many as 8,000 in one flock. Manuwal (1977) listed greater scaup as the third most abundant diving species observed during his seven ferry transect surveys through the San Juan archipelago.

Littoral and shallow sublittoral molluscs and crustaceans appear to constitute the diet of greater scaup foraging in marine environments (Salo 1975), although these birds are also reported to congregate near spawning Pacific herring in March and April (Munro 1941b). Martin and Uhler (1939) listed the native oyster, Ostrea lurida, along the Washington coast as one of the principal food items of greater scaup.

Lesser Scaup

Salo (1975), using information from Munro (1941b), Jewett, et al. (1953), Bakus (1965), and Alcorn (1971), suggests that lesser scaup are distributed mainly in freshwater habitats during their winter residency in northern Puget Sound; several sources, however, had documented lesser scaup occurring commonly on the region's marine waters. The 1976 Audubon Christmas bird count (Heilbrum, et al., 1977), in fact, included high counts at both Vancouver (452) and Victoria (1,012), B.C. Although preference for aquatic and marsh plants was shown by Munro (1941b) and Martin, et al. (1951), the diet of lesser scaup in marine waters may, like greater scaup, be oriented toward invertebrates such as molluscs and crustaceans (Rogers and Korschgen 1966).

Common Goldeneye

Common goldeneye was considered a common migrant and winter resident by Munro (1939), Jewett, et al. (1953), and Salo (1975). These birds typically occur in the channels and small bays in flocks of 20 to 30 individuals, often in association with other diving ducks. Drayton Harbor and Birch Bay in northeast Puget Sound appear to harbor the greatest wintering abundance of any of the sites surveyed by the Washington Department of Game in north Puget Sound and the Strait of Juan de Fuca (R.C. Parker, Wash. Dept. Game, unpubl. data). Kortright's (1942) analysis of 395 common goldeneye stomachs indicated that crustaceans (32%) and insects (28%) were the major prey taxa, followed by molluscs (10%) and plant (pondweed 9%) remains.

Barrow's Goldeneye

Generally thought less abundant than the common goldeneye, Barrow's goldeneye are similarly distributed as migrants and winter residents throughout the north Puget Sound region (Munro 1939; Alcorn 1971; Salo 1975). Populations wintering in the Strait of Georgia may be more numerous, as evidenced by the 1976 Audubon Christmas bird count (Heilbrum, et al., 1977), wherein over 2,000 individuals were counted at Nanaimo, B.C., and 1,269 at Vancouver, B.C. Insects (36%), and especially molluscs (19%) and crustaceans

(18%), are important food taxa for Barrow's goldeneye occupying marine habitats (Kortright 1942; Salo 1975).

Bufflehead

Bufflehead appear to be widely distributed, abundant migrant and winter residents, characterizing shallow, sheltered marine habitats (Munro 1942; Jewett, et al., 1953; Erskine 1971; Salo 1975). They appear to be especially concentrated in northeastern Puget Sound, where flocks of 3,800 to 12,800 birds are reported, and Dungeness Bay, where peak abundances of 4,600 birds are recorded in December (Salo 1975). Abundances reported at Sequim Bay peaked at over 300 during October-November and March but remained between 135 and 150 during the rest of the winter (D. Moriarity and S. Oliver, Graysmarsh Wildlife Refuge, pers. comm.). The maximum counts in the 1976 Audubon Christmas bird count were at Victoria (1,198), Bellingham (656), and Dungeness Bay (581) (Heilbrum, et al., 1977). In marine habitats, crustaceans, molluscs, and to a lesser extent, small fish appear to be the most important food items (Munro 1942; Salo 1975); herring eggs laid in shallow sublittoral waters may also be consumed when available in the spring.

Oldsquaw

Also a migrant and winter resident, oldsquaw in Washington State occur rather uniformly though sparsely throughout north Puget Sound and the Strait of Juan de Fuca (Kortright 1942; Jewett, et al., 1953; Larrison and Sonnenberg 1968; Alcorn 1971; Salo 1975). Kortright (1942) listed crustaceans (48%), molluscs (16%), insects (11%), and fish (10%) as the primary prey taxa found in 227 stomachs. Like many of the other diving ducks, oldsquaw have been observed foraging on the eggs of Pacific herring in the spring (Jewett, et al., 1953).

Harlequin Duck

Harlequins appear to be one of the few diving ducks which are year-long residents in the State, although many of those inhabiting Puget Sound in winter may include migrants (Jewett, et al., 1953; Alcorn 1971; Salo 1975). They occur in congregations of up to 200 birds along rocky shores of the San Juan Islands, Dungeness Spit and Bay, and along the northern shore of the Olympic Peninsula. Crustaceans (57%) and molluscs (25%) composed the diet of 64 harlequins examined by Kortright (1942, cited in Salo 1975).

White-Winged Scoter

A common and often the most abundant sea duck in winter in Washington's inland and coastal waters, white-winged scoters have been estimated to number up to 42,000 birds (Jewett, et al., 1953; Alcorn 1971; Salo 1975). Manuwal (1977) reported this species as the second most abundant over all seven ferry transect surveys conducted between November 1973 and April 1974 in the San Juan Islands. They tend to be more abundant in the eastern Strait of Juan de Fuca; approximately 400 are observed during October-November in Sequim Bay and they are also common at Dungeness Spit (D. Moriarity and S. Oliver, Graysmarsh Wildlife Refuge, pers. comm.; 1977 Olympic Pen. Audubon Soc. Christmas Count Newsletter, unpub.).

One specimen collected in Grays Harbor had eelgrass in its esophagus (Smith and Mudd 1976). Cottam (1939) described the stomach contents of 819 white-winged scoters collected in the Pacific Northwest. They contained 75% bivalve molluscs (Manila clams, Tapes japonica, Olympia oysters, blue mussels, and scallops), 13% crustaceans, and incidentally fish and insects. In Puget Sound they have been observed foraging over shallow-water commercial clam and oyster beds and on herring eggs (Jewett, et al., 1953; Salo 1975).

Surf Scoter

Surf scoters are generally similar to white-winged scoters in occurrence, distribution, and abundance (Jewett, et al., 1953; Salo 1975). According to the 1976 Audubon Christmas bird count, in fact, they were more numerous at Nanaimo (1,943), Vancouver (2,160), Victoria (361), Bellingham (417), and Everett (58) (Heilbrum, et al., 1977). Salo (1975) included reports of 2,400 to 3,000 birds at Dungeness Spit between September and November, 40,000 at Destruction Island in October, and 1,200 in the San Juan Islands in December. Manuwal (1977) designated surf scoters as the sixth most numerous diving species observed along his ferry transect surveys, winter 1973 to spring 1974.

The prey of surf scoters examined by Cottam (1939) was primarily molluscs (61%, 29% of which were blue mussels), crustaceans (10%), and insects (10%). The stomachs of 21 surf scoters from Dabob Bay, Washington, contained primarily Manila clams, but blue mussels and soft-shell clams, Mya arenaria, and Macoma sp. clams also occurred (Glude 1967).

Black Scoter

Black scoters appear to be less abundant than the other two scoter species, and tend to be distributed more along the exposed coast (Salo 1975). Black scoters were sighted during the 1976 Audubon Christmas bird count in the Strait of Georgia--e.g., Nanaimo (280) and Vancouver (342) (Heilbrum, et al., 1977). October and May appear to be the peak fall and spring migration periods (Kortright 1942). Cottam's (1939) analysis of the contents of 124 black scoter stomachs indicated that 65% was molluscs (27% blue mussel, 7% razor clam, Siligua patula, 6% oysters, Ostrea lurida?, and 5% littleneck clams), 17% crustaceans, and 3% insects. Glude (1967) identified Manila clams, blue mussels, and barnacles (Balanus sp.) in the stomachs of scoters feeding in Dabob Bay, Washington.

Common Merganser

Though common mergansers reside in terrestrial aquatic habitats through the spring and summer, they congregate in marine and estuarine habitats during fall and winter (Jewett, et al., 1953; Salo 1975). Nanaimo, Pender Islands, Victoria, and Vancouver, B.C., all had between 100 and 200 sightings during the 1976 Audubon Christmas bird count (Heilbrum, et al., 1977) and 300 have been sighted at Dungeness Spit (Salo 1975). Yet, little quantitative diet information exists for the common merganser. It is assumed to dive for and consume small fishes, apparently including juvenile salmon (Salo 1975). Small demersal fishes (cottids, pholids, stichaeids, pleuronectids) and schooling neritic fishes (Pacific herring, Pacific sand lance) may also be consumed.

Red-Breasted Merganser

The red-breasted merganser is more of a migrant and winter resident than the common merganser. It occupies north Puget Sound waters between September and April and reaches maximum abundance in November (Salo 1975). As many as 125 birds were seen forming one premigration flock at Dungeness Spit in April and 141 birds were observed there in December 1977 (1977 Olympic Pen. Audubon Soc. Christmas Count Newsletter, unpub.). Fish (sculpin and Pacific herring) and crustaceans are important prey items for red-breasted mergansers foraging in marine habitats, and they have been observed to concentrate on spawning Pacific herring during February and March (Munro and Clemens 1939; Kortright 1942; Salo 1975).

Osprey

Ospreys do not appear to frequent marine habitats of Washington, except in the San Juan Islands where they occur from April to October (Retfalvi 1963; Bakus 1965). Fishes are generally considered to be the basic prey of ospreys (Bent 1937; Salo 1975).

Bald Eagle

Although they do not actually occupy the marine waters, bald eagles at times forage in the nearshore environment, and thus periodically appear as upper trophic level consumers in those food webs. Of the 221 bald eagle nests reported in a 1975 survey of western Washington (Grubb, et al., 1975), 47% (103 nests) were located in the San Juan Islands and 26% (57 nests) were located in the northern section of the Olympic Peninsula; between 60% and 64% of these nests were considered successful. Despite increased human activity in the vicinity of nests on San Juan Island reported by Retfalvi (1965), Newman, et al. (1977), reported a 100% increase in eagle nests between 1962-63 and 1975.

Although they commonly scavenge for food, bald eagles raid seabird colonies, taking gulls, guillemots, cormorants, and puffins (Campbell 1969; Salo 1975), and capture benthic invertebrates such as crabs (Pugettia producta), sea urchins (Strongylocentrotus sp.), and abalone (Haliotis kamschatkana), and fish, including salmon (Oncorhynchus sp.), Pacific herring, Dolly Varden (Salvelinus malma), cutthroat trout (Salmo clarki), Pacific halibut (Hippoglossus stenolepis), and sculpin (Hawbecker 1958; Campbell 1969; Ofelt 1975; Salo 1975).

Great Blue Heron

Commonly observed singly or in small groups in shallow waters of tide flats and estuaries, great blue herons are distributed throughout north Puget Sound and eastern Strait of Juan de Fuca (Bakus 1965; Salo 1975). In general, great blue heron prey on aquatic and estuarine animals, including fish, amphibians, and crustaceans, but also insects and small terrestrial mammals

(Martin, et al., 1951; Jewett, et al., 1953; Lowe 1954; Meyerriecks 1962). Those studied by Krebs (1974) on the Fraser River delta near Vancouver, B.C., had consumed either staghorn sculpin or starry flounder (Platichthys stellatus), these two species accounting for 67% of all prey. Other incidental prey were shiner perch, penpoint gunnel, and shrimp. Although great blue heron typically forage in shallow waters, one was observed by Godin (1977) to effectively capture 5-9 cm long shiner perch while standing on a platform floating over 10 m of water.

Virginia Rail

These rather rare shorebirds are found on Pacific Northwest estuaries, tideflats, and sand beaches in winter (Robbins, et al., 1966). Heilbrum, et al. (1977), included reports of one Virginia rail each at Vancouver and Victoria, B.C., during the December 1976 Audubon count. Little information is available on their diet; it is assumed that, as in the diets of other shorebirds, shallow-water crustaceans may be important.

American Coot

Coots are common resident birds in Washington and British Columbia which winter in sheltered marine habitats (Jewett, et al., 1953; Alcorn 1971; Salo 1975). Large aggregations have been reported throughout north Puget Sound and the Strait of Juan de Fuca, especially in the semi-urban areas near Vancouver and Victoria, B.C., and Bellingham, Washington (Salo 1975; Heilbrum, et al., 1977). The stomach of one American coot collected in Grays Harbor by Smith and Mudd (1976) contained eelgrass and a small amount of algae.

Black Oystercatcher

Black oystercatchers are common residents of the coastal regions of western Washington, usually frequenting the rocky exposed shoreline and nesting on the islands and islets along the Pacific coast of the Olympic Peninsula and in the San Juan and Gulf islands (Salo 1975). Eighty to 100 pairs were estimated to nest on the coastal islets of the Washington Islands National Wildlife Refuge, 80 pairs in the San Juan Islands, and approximately 90 pairs in the Gulf Islands. Ninety-two to 100 breeding pairs were estimated for the outer coast and 25 to 34 for the San Juan Islands and the Strait of Juan de Fuca in Manuwal's (1977) survey. Principal nesting locations included Long, Protection, and Smith islands.

Marine gastropods and bivalves, e.g., limpets, mussels, and chitons, of rocky littoral habitats constitute the common prey of black oystercatchers (Jewett, et al., 1953). Webster (1941) estimated that their diet in southeastern Alaska was composed of 30% ribbed limpets, Collisella digitalis; 20% blue mussels (Mytilus edulis; 15% California mussels, M. californianus; 15% gooseneck barnacles, Pollicipes polymerus; 13% shield limpets, Notoacmea scutum; 5% black chitons, Katharina tunicata; 1% duncecap limpets, Acmaea mitra; and polychaete annelids, Nereis sp. Hartwick (1973) indicated that while mussels formed the greatest part by weight of the oystercatcher's diet, crabs were of importance when chicks were present.

Semipalmated Plover

Salo (1975) considered the semipalmated plover a common migrant in western Washington, frequenting sandy beaches and tideflats during spring (April-May) and fall (September-October). Large flocks of up to 1,000 birds have been reported along the eastern end of the Strait of Juan de Fuca and in the San Juan Islands during these periods. Wintering birds, however, may be uncommon. Heilbrum, et al. (1977), reported only two birds during the 1976 Audubon Christmas bird count in the San Juan Islands and the Strait of Juan de Fuca. Bent (1929) listed littoral invertebrates (molluscs such as *Littorina* sp. and *Mytilus* sp. and crustaceans such as *Gammarus* sp., *Limnoria* sp., and *Orchestria* sp.) and insects as the principal food organisms of semipalmated plovers.

Whimbrel

Whimbrels apparently are common only during their fall (August) and spring (May) migration periods, when 100 to 170 birds have been counted in the Washington Islands National Wildlife Refuge and the San Juan Islands (Salo 1975). Bent (1929) and Jewett, et al. (1953), described the diet of wintering whimbrels as including polychaete annelids, molluscs, and crustaceans.

Spotted Sandpiper

Although some spotted sandpipers winter in Washington, most are summer residents which breed in the region (Jewett, et al., 1953; Alcorn 1971; Salo 1975). When present in marine habitats, principally sand and gravel beaches and mudflats, spotted sandpipers eat mostly benthic invertebrates, including polychaete annelids, gammarid amphipods, and molluscs.

Wandering Tattler

Jewett, et al. (1953), and Salo (1975) consider the wandering tattlers as locally common migrants, most often observed in rocky shoreline habitats of the exposed coast, the Strait of Juan de Fuca, and the San Juan Islands. Their diet according to Bent (1929) includes small molluscs, crustaceans, polychaetes, and insects.

Short-Billed Dowitcher

Although migrants to Washington, short-billed dowitchers are commonly observed along the coast and through the Strait of Juan de Fuca to the San Juan Islands. The peak spring migration is in April and May and the peak of the fall migration is in September and October (Larrison and Sonnenberg 1968; Salo 1975). They feed in small flocks of 10 to 50 birds in sand and mudflat habitats, extracting marine annelids, flatworms, small molluscs, fish eggs, and occasional plant matter from the shallow waters (Salo 1975).

Sperry's (1940) analysis of the stomach contents of 191 short-billed dowitchers, collected mostly from the Atlantic coast of the United States, indicated that insects (29.1%, including 18% dipteran larvae, primarily

Stratiomyiidae, Empididae, and Tabanidae, and 8.9% Coleoptera, including aquatic Hydrophilidae and Dytiscidae), marine annelids (27.4%, including Nereis sp.), and marine molluscs (20.9%, including Melampus sp. and nassariid snails among the gastropods; and Gemma gemma, Ostrea virginica, Mytilus edulis, and Venus mercenaria among the bivalves) were the principal components of their diet. Crustaceans, including crabs (Uca sp.), shrimp (Crago sp.), isopods (Cynthura carinata), ostracods, and amphipods, and horseshoe crab (Limulus polyphemus) eggs were also found to a lesser degree in the stomach contents of short-billed dowitchers.

Long-Billed Dowitcher

Although considered less common than short-billed dowitchers, migrant long-billed dowitchers have been observed in great numbers in the coastal embayments of Washington and are assumed to occur frequently in the San Juan Islands (Salo 1975). Small flocks may overwinter in the region, as evidenced by the 1976 Audubon Christmas bird count (Heilbrum, et al., 1977) which included 17 individuals observed at Victoria, B.C.

Jewett, et al. (1953), and Salo (1975) assumed that long-billed dowitchers feed upon coastal marine invertebrates--e.g., annelids, small crustaceans, and molluscs--and some plant matter. The majority of the 107 stomach samples examined by Sperry (1940) were collected in inland areas, but marine annelids (Nereis sp.), crustaceans (amphipods, including Echinogammarus ochotensis and Corophium spinicorne, and the isopod Exosphaeroma oregonensis), and molluscs (gastropods, including Littorina sitchana) were included as prey items. Smith and Mudd (1976) collected only a few specimens in Grays Harbor. Examination of the esophagus of one specimen indicated amphipods (Corophium sp.) and polychaetes were important prey but further examination of the gizzard (which biases toward hard-food organisms) suggested that clams (Macoma inconspicua and Mya arenaria) were also important.

Surfbird

Surfbirds migrate into western Washington in August and reside on rocky shores and gravel beaches until April (Jewett, et al., 1953; Salo 1975). They are most common along the exposed coast and rarer around Puget Sound. The 1976 Audubon Christmas bird count (Heilbrum, et al., 1977) in this region recorded surfbirds in abundance only at Nanaimo, B.C. Crustaceans and small molluscs of the rocky littoral zones are the prey of surfbirds (Bent 1929).

Ruddy Turnstone

Ruddy turnstones, though fairly common migrants along the exposed coast, are uncommon inside the Strait of Juan de Fuca and rarely over-winter in this region (Salo 1975). Their diet resembles that of the sandpipers, i.e., polychaetes, molluscs, and crustaceans of beaches and mudflats (Bent 1929; Jewett, et al., 1953; Salo 1975).

Black Turnstone

Black turnstone is much more common than its congener ruddy turnstone and is locally abundant in northern Puget Sound and the Strait of Juan de Fuca as a migrant and winter resident (Jewett, et al., 1953; Salo 1975). Heilbrum's, et al. (1977), account of the 1976 Audubon Christmas bird count listed black turnstones at almost all stations in this region, but the highest counts were at Victoria (212) and Vancouver (147), B.C. Molluscs (limpets), barnacles, and other crustaceans common to the rocky littoral zone are the basic prey items of black turnstones (Bent 1929; Jewett, et al., 1953).

Greater Yellowlegs

Migrating greater yellowlegs occur in the region in April-May and July-August, and are most common in northern Puget Sound (Jewett, et al., 1953; Salo 1975; Heilbrum, et al., 1977). The highest count of overwintering birds during the 1976 Audubon Christmas bird count was 34 at Victoria, B.C. Jewett, et al. (1953), described their food as including molluscs, crustaceans, and small fish.

Rock Sandpiper

Larrison and Sonnenberg (1968) described rock sandpipers as uncommon to rare spring and fall migrants, although there may be some casual winter residency (Alcorn 1971). Although little is known of their diet, small crustaceans, molluscs, and insects are assumed to be important (Eaton 1975).

Dunlin

Dunlins are often one of the most common shorebirds encountered on the coast of Washington, especially on the region's extensive mudflat habitat. Dunlin dominated the shorebirds (almost 2,800 birds counted) at Dungeness Spit during the 1977 Audubon Christmas bird count (1977 Olympic Pen. Audubon Soc. Christmas Count Newsletter, unpub.).

Couch (1966) reported that wintering dunlins in northern Puget Sound consumed mostly amphipods, especially *Anisogammarus confervicolus* at low tide and *Orchestoidea pugettensis* at high tide. Benthic invertebrates, mainly amphipods (69.7% of total number of identifiable prey, including *Corophium* sp., 52.5%; *Anisogammarus confervicolus*, 16.5%; and *Amphitoe* sp., 0.7%), polychaete annelids (8.5% of identifiable prey, including *Nereis* sp., *Streblospio benedicti*, *Amphicteis mucronata*, and *Eteone longa*), oligochaete annelids (3.2%), molluscs (1.9%, including *Macoma inconspicua* and *Mya arenaria*), tanaids (0.7%, *Pancolus californiensis*), and unidentified nematodes (1.5%), were the principal prey of dunlins wintering in Grays Harbor (Smith and Mudd 1976). It was also determined that during high tide, dunlins supplemented the invertebrate-based diet with seeds of the saltmarsh plants *Spergularia marina* and *Triglochia maritinum*. Few differences were noted in diet composition among five sampling sites.

Recher's (1966) analysis of the contents of 46 stomachs of dunlin collected in California documented the nereid polychaete Nereis diversicolor as the principal prey (70% frequency of occurrence), followed by ostracods and amphipods. Studies by Bengtson and Svensson (1968) in southern Sweden, and Ehlert (1964, cited in Kawaji and Shiraishi 1979) in the Baltic Sea (Helgoland) illustrated generally the same preference for N. diversicolor. The data provided by Madon (1935, cited in Wolf 1969) indicated that in addition to N. diversicolor, molluscs, crustaceans, insects, and vegetable matter were also important in the stomachs of dunlin along the Atlantic coast of France. The Wild Bird Society of Japan (1975, cited in Kawaji and Shiraishi 1979) and Kawaji and Shiraishi (1979) found that the polychaete annelid Neanthes japonica; the gastropod molluscs Fluviocingula nipponica, Salinator takii, and Ellobium chinense; and the bivalve mollusc Musculus senhousia supplied the principal food items in nearshore regions of Japan. Davidson (1971) showed a similar diet composition for dunlin collected in Morecambe Bay, Lancashire, England.

The only deviation from the above documentation of benthic polychaetes and molluscs as principal prey was that of Holmes's (1966) description of dunlin food habits during its breeding season in arctic Alaska, when it utilized larval and adult dipteran insects.

Knot

Both the American knot (Calidris canutus rufus) and the Pacific knot (C.c. rogersi) are found in Puget Sound infrequently (Alcorn 1971; Jewett, et al., 1953; Salo 1975). When observed they are often in large flocks on tidal flats and along the sand beaches of exposed coasts. The stomachs of 219 American knots collected from the east coast of the United States (Sperry 1940) contained, by volume, 59% molluscs (mainly Nassariidae, Littorina sp., and Melampus sp. among the univalves, and Donax sp., Gemma gemma, Mytilus edulis, and Modiolus demissus among the bivalves); 14.8% insects (including 12.7% Diptera, i.e., Stratiomyiidae, Ephydridae, Tabanidae, Empididae, and Tipulidae; 1.2% Coleoptera, i.e., Hydrophilidae; and 0.9% other insects, i.e., Formicidae, Pentatomidae, and Cydnidae); 8.9% crustaceans (including crab eggs); 2.2% fish, marine annelids, and other incidental animals; and 15.2% plants (primarily seeds of widgeongrass and other estuarine plants).

Least Sandpiper

Least sandpipers, common migrants and occasional winter residents in this region, are quite abundant along the outer coast but also occur frequently at Dungeness Spit and in the San Juan Islands (Jewett, et al., 1953; Alcorn 1971; Salo 1975). April and May mark the spring migration, August-September, the fall migration. Winter residents may be uncommon in northern Puget Sound as few were reported during the 1976 Audubon Christmas bird count (Heilbrum, et al., 1977). The principal food of least sandpipers feeding on beaches and mudflats is the amphipod Anisogammarus confervicolus (Couch 1966). Sanger (1970) indicated that elevated mudflats were preferred foraging areas at high tide, whereas sandier mudflats were utilized during low tide.

Western Sandpiper

Western sandpipers are common spring and fall migrants in north Puget Sound, occurring in April and May and again in July through December. Small flocks are especially common in the San Juans and at Dungeness Spit (Jewett, et al., 1953; Alcorn 1971; Salo 1975; Heilbrum, et al., 1977).

Smith and Mudd (1976) listed a wide variety of prey items of western sandpipers wintering in Grays Harbor. Polychaete annelids (24.4%, including Streblospio benedicti and other unidentified spionids and Eteone longa), nematodes (13.3%), amphipods (8.9%, Euhaustorius washingtonius), adult and larval insects (6.7%), and tanaids (2.2%, Pancolus californiensis) composed the animal prey items, whereas saltmarsh plant seeds (40%, primarily Spergularia marina but also including Triglochia maritimum and Deschampsia cespitosa) were the main diet when the birds fed at high tide. Western sandpipers collected from the San Juan Islands and other Pacific Northwest sites had eaten mostly amphipods, including Anisogammarus confervicolus and Corophium sp. (Couch 1966).

Sanderling

Sanderlings are common migrants and winter residents which form large (e.g., 5,000 birds) flocks on the outer coast but smaller (e.g., 50) flocks in north Puget Sound (Jewett, et al., 1953; Alcorn 1971; Salo 1975). They were especially numerous at Bellingham and Dungeness Spit during the 1976 Audubon Christmas bird count (Heilbrum, et al., 1977). Amphipods (Anisogammarus confervicolus, Orchestoidea pugettensis) and bivalve molluscs (razor clams on the outer coast) are their usual prey organisms (Cough 1966).

Wilson's Phalarope

Wilson's phalarope is a casual summer migrant and resident which migrates to the area in May and leaves in August (Jewett, et al., 1953; Alcorn 1971; Salo 1975). Jewett, et al. (1953), listed insects and their larvae as the major food of sanderlings, although small crustaceans and plants may also be consumed (Bent 1927).

Northern Phalarope

A much more common migrant than Wilson's phalarope, the northern phalarope occurs in high numbers (10,000-17,000 birds) in northern Puget Sound in May and August as well as offshore (Jewett, et al., 1953; Salo 1975). While insects appear to form much of the diet (80%), small crustaceans (9%), polychaete annelids, small molluscs and fish, and plant material also occurred in their diet (Bent 1927).

Parasitic Jaeger

Parasitic jaegers occur in Washington's marine habitats frequently during their spring (April-May) and fall (July-December) migration through the region (Jewett, et al., 1953; Alcorn 1971; Salo 1975). Since they commonly obtain food by harassing gulls and terns into dropping or disgorging their food, parasitic jaegers are ultimately linked to the food resources of gulls and terns (Salo 1975).

Pomarine Jaeger

Little information is available on the distribution or relative abundance of pomarine jaegers in the region. Guiget (1971a) states that they appear offshore of Vancouver Island, B.C. in small numbers in mid-July increasing through September; occurrence in inland waters is apparently scarce. Although they capture small birds and rodents, when in marine environments they appear to gain most of their food by robbing gulls, terns, and other marine birds.

Glaucous-Winged Gull

Glaucous-winged gulls have been described as the most commonly observed gull in nearshore areas along the Washington coast (Sanger 1965) but are encountered in abundance offshore only during November and January (Sanger 1970). Manuwal's (1977) survey of the breeding seabirds in Washington State included an estimate of 6,234 breeding pairs in the San Juan Islands and the Strait of Juan de Fuca; the largest populations included colonies on Colville and Protection islands. They were the most prominent gull species surveyed at Dungeness Spit in December 1977, totaling almost 600 birds (Olympic Pen. Audubon Soc. 1977 Christmas Count Newsletter, unpub.).

Outram (1958) listed glaucous-winged gulls as one of the major causes of herring egg mortality; the stomachs of 12 gulls that he examined contained an average of 13,800 eggs. Fish, primarily capelin (*Mallotus villosus*) occurred in the stomachs of 33% of the glaucous-winged gulls collected in Alaskan waters by Sanger and Biard (1977). Pollock averaging 20 cm in length were found in the stomachs of gulls associated with the Bering Sea pack ice in April (Divoky, et al., 1977). James-Veitch and Booth (1954) listed chitons, sea cucumbers, sea urchins, crabs (*Cancer* sp., *Hemigrapsus* sp.), blue mussels, and polychaete worms (*Nereis* sp.) as prey of foraging glaucous-winged gulls.

Western Gull

Western gulls are the most common residents of Washington's outer beaches and non-breeding gulls are common through the Strait of Juan de Fuca and northern Puget Sound (Jewett, et al., 1953; Alcorn 1971; Salo 1975). Hunt and Hunt (1976) examined the food items of western gull chicks on Santa Barbara Island, California. They found that 89% of the food was composed mostly of schooling fishes, and included northern anchovy (45% frequency occurrence), jack mackerel (*Trachurus symmetricus*, 5.2%), Pacific saury (*Cololabis saira*, 2.8%), midshipman (*Porichthys* sp., 1.9%), and squid.

Herring Gull

The common, ubiquitous herring gull occurs in every habitat of northern Puget Sound and the Strait of Juan de Fuca and is especially well adapted to urban coastal areas (Jewett, et al., 1953; Salo 1975). Verbeek (1977) established that in the Cumbria, England, area, immature herring gulls relied more on stealing than on foraging, until they developed feeding skills, whereupon starfish became the principal food item. Herring gull predation upon spawned herring eggs in British Columbia was reported by Outram (1958), who documented an average of 8,500 eggs per stomach for the nine stomachs examined.

California Gull

California gulls occur in western Washington in abundance during their fall and spring migrations and small numbers overwinter in Puget Sound (Jewett, et al., 1953; Alcorn 1971; Salo 1975). Though observed frequently, they were not very abundant during the 1976 Audubon Christmas bird count (Heilbrum, et al., 1977). As many as 1,000 have been recorded at Dungeness Spit in August (Salo 1975). Though the California gull apparently is as omnivorous as the other gulls (Jewett, et al., 1953; Salo 1975), it also preys specifically on juvenile sea or shore birds (Chura 1962).

Ring-Billed Gull

Ring-billed gulls are common winter residents in western Washington and non-breeding birds may be found throughout the summer (Alcorn 1971; Salo 1975; Eaton 1975). Like the other large gulls, ring-billed gulls consume almost anything available and edible, including small fish, refuse, insects, and small rodents and birds (Guiguet 1971a; Salo 1975; Eaton 1975).

Mew Gull

Mew gulls are common winter residents along the Pacific Northwest coast from October to April. Despite its common occurrence in this region, few data on its food habits exist. In Alaskan waters they feed mainly on unidentified crustaceans (83% frequency occurrence) and much less on fishes (17%) (Sanger and Baird 1977), but are documented as feeding primarily on small fishes when wintering in north Puget Sound and the Strait of Juan de Fuca (Guiguet 1971a).

Heermann's Gull

As a common summer migrant, Heermann's gulls are most abundant in Puget Sound from August to October (Alcorn 1971; Guiguet 1971a; Salo 1975). Schooling neritic fishes, such as Pacific herring, or those of kelp beds are the most common food organisms of Heermann's gulls, but they are also known to parasitize Bonaparte's gulls and cormorants (Guiguet 1971a; Salo 1975).

Bonaparte's Gull

Bonaparte's gull occurs in Washington's marine waters primarily as a migrant and winter resident, reaching peak abundance in October (Salo 1975). Counts in the San Juan Islands National Wildlife Refuge included approximately 7,000 in April and up to 15,000 in August. Wahl (1977) reported that after high abundances in October and November, only a few hundred were seen at Active Pass, B.C., until April and May when the northward-migrating gulls passed through.

Little detailed information exists on the diet of Bonaparte's gull. Jewett, et al. (1953), recorded that at times insects form the majority of its prey. Salo (1975) suggested that "small fish and other marine life" generally composed the diet. Guiguet (1971a) reported that small Pacific herring and Pacific sand lance, forced to the surface by feeding salmon, were fed upon by Bonaparte's gulls.

Sabine's Gull

Sanger (1965) reported one or two Sabine's gulls within five miles of the Washington and Oregon coast during September and October, but it is doubtful that they frequent the inshore waters of the Strait of Juan de Fuca or northern Puget Sound (D. Manuwal, pers. comm.). Guiguet (1971a) reported that Sabine's gulls feed upon crustaceans, small fishes, and marine annelid worms.

Black-Legged Kittiwake

Kittiwakes winter well offshore the coasts of Washington and British Columbia but may occasionally be encountered inshore, especially during storm periods (Gabrielson and Jewett 1940; Jewett, et al., 1953; Sanger 1970). Sanger and Baird (1977) examined the stomachs of 21 of 76 specimens collected in Alaskan waters between 1969 and 1976. Fish (Pacific sand lance, 43% freq. occur., and Pacific herring, 14%) occurred in 76% of these stomachs, crustaceans (the hyperiid amphipod *Parathemisto libellula*, 29%, and the euphausiid *Thysanoessa raschi*, 14%) in 19%, and squid in 5%.

Both fish and invertebrates entered the diet of black-legged kittiwakes collected in the Cape Thompson vicinity of Alaska (Springer and Roseneau 1977). Fishes included polar cod (*Boreogadus saida*, 33% freq. occur.), saffron cod (*Eleginus gracilis*, 33%), flatfish (7%), and ninespine stickleback (*Pungitius pungitius*, 7%); and invertebrates included gastropods (Trochidae, 13%), crabs (13%), nereid polychaetes (7%), shrimp (*Pandalus goniurus*, *P. montagui*, *Pandalus* sp., and *Eualus gaimardi*, 7% each), isopods (*Saduria entomon*, 7%), and insects (7%).

Fish (principally cod and capelin) and euphausiids (*Thysanoessa inermis*, *T. longipes*, *T. raschi*, and *T. spinifera*) were the main prey items of kittiwakes collected in the Pribilof Islands (Hunt 1977). Birds feeding along the southern edge of the Bering Sea icepack in March and April had consumed capelin and walleye pollock (*Theragra chalcogramma*) (Divoky, et al., 1977). The diet of black-legged kittiwakes of the Farne Islands in Great Britain was almost completely composed of fish (98% prey abundance, 99% biomass), primarily sand lance (Ammodytidae), herring (Clupeidae), and cod (Gadidae).

Common Tern

Whereas common terns migrate rapidly along the Pacific coast in the spring, the fall migration during August to October brings them to the coastal and Strait of Juan de Fuca areas (Jewett, et al., 1953; Alcorn 1971; Salo 1975). Salo (1975) reported 250 common terns observed at Dungeness Spit in August. Common terns feed mainly on small neritic fishes (Salo 1975) which in this region would include Pacific herring, Pacific sand lance, smelt (Osmeridae), and juvenile salmon.

Arctic Tern

Arctic terns are common migrants along the Pacific Northwest coast and in north Puget Sound (Guiguet 1971a). A small breeding colony (7-12 pairs) has been reported to occur on Jetty Island near Everett, Washington (D. Manuwal, pers. comm.). Crustaceans (unidentified) occurred in 100% of the stomachs of birds collected by Sanger and Baird (1977) from Alaskan waters between 1969 and 1976. Pacific sand lance and herring composed the majority of the prey abundance (87%) and biomass (85%) of arctic terns in the Farne Islands of Great Britain (Pearson 1968).

Caspian Tern

Although at the approximate northern extremity of their West Coast distribution, Caspian terns are common, both as fall migrants and as breeding birds (approximately 2,500), on the outer Washington coast (Robbins, et al., 1966; Eaton 1975). Smith and Mudd (1976) reported the species composition of 31 fish removed from a Grays Harbor ternery. Shiner perch composed over half of the fish collected; juvenile chum salmon (*Oncorhynchus keta*) and Pacific staghorn sculpin were also common; white seaperch (*Phanerodon furcatus*), whitebait smelt (*Allosmerus elongatus*), snake prickleback, cutthroat trout, and longnose dace (*Rhinichthys cataractae*) were also found. Bent (1921) also suggested shrimp, mussels, and eggs and young of other birds as prey items.

Common Murre

Common murres breed in large concentrations in crevices or on steep cliffs, on the large stacks and islands of the outer coast, especially around LaPush, Washington (Cody 1973), and are very abundant in the Strait of Juan de Fuca from August through October. Manuwal (1977) documented 11,950 pairs of common murres nesting on the outer coast of Washington. The largest breeding populations were located in the Point Grenville and Willoughby Rock vicinities.

The best documentation of common murre prey spectrum is in Scott's (1973) study at Yaquina Head, Oregon. His results substantiated earlier reports by Belopol'skii (1957) and Bedard (1969) that common murres feed mainly on midwater fishes. Scott's study indicated that eulachon (*Thaleichthys pacificus*) and northern anchovy were the most important prey of the regon. Juvenile rockfish became a major constituent of the diet of fledglings after they had left the breeding rocks. In one year, however, epibenthic crustaceans (euphausiids, mysids) constituted 86.2% of the total prey volume, a result that Scott attributed to the lack of midwater schooling fishes in the area at that time. Using Scott's data, Wiens and Scott (1975) calculated the total animal energy demand of common murres off Oregon to be 3.488 k cal m^{-2}, the highest of the four species they examined.

Steele and Drury (1977), Hunt (1977), and Sanger, et al. (1977), also documented the importance of midwater fishes in the prey spectrum of common murres in Alaskan waters. The principal prey species were capelin, Pacific sand lance, walleye pollock, a prickleback (Lumpenus fabrici), and several other unidentified cod and smelt. Fish, primarily Pacific sand lance, occurred in 77% of the stomachs examined from Alaskan waters by Sanger and Baird (1977); crustaceans (unidentified) occurred in only 15%.

Common murres in the Cape Thompson vicinity of Alaska appeared to utilize primarily polar cod (42% freq. occur.), saffron cod (33%), Pacific sand lance (17%), and unidentified sculpins (17%) (Springer and Roseneau 1977). Murres collected over the Bering Sea pack ice in March by Divoky, et al. (1977), had consumed 7.5-18 cm long pollock and 10-14 cm long capelin, but the hyperiid amphipod Parathemisto sp. occurred the most frequently in the stomach, though providing less than one percent of the total prey volume; euphausiids appeared more often (57% freq. occur., 20.4% volume) in April.

Tuck's (1960) summary analysis of the diet of North Atlantic murres also confirmed that they eat midwater schooling fishes, specifically gadids (cod and haddock), sand lance, herring, and capelin, but also included such diverse benthic fishes as sculpin and flatfish. Although they were not a significant proportion of the total prey volume, a variety of invertebrates (shrimp and cephalopod molluscs) also occurred in the diet. Common murres in the Pembrokeshire region of Great Britain were observed to feed their chicks sand lance and small herring (Clupea sprattus) in the 50-175 mm size range (Harris 1970).

Pigeon Guillemot

Pigeon guillemot is ubiquitous throughout the region, breeding in small colonies on high cliffs both offshore and inshore (Cody 1973). Manuwal (1977) estimated 161 breeding pairs along the outer Washington coast and 194 pairs in the San Juan Islands and the Strait of Juan de Fuca; prominent colonies in the latter region include Castle, Protection, Skipjack, and Smith islands. They were tenth in total abundance of the diving birds observed during the San Juan Island ferry transect surveys.

In Cody's (1973) ecological analysis of Washington's alcid communities, the pigeon guillemot's diet is distinguished from the other alcids' diets by its dependence on shallow sublittoral fishes, specifically "blennies" (Pholidae and Stichaeidae?), and clingfish (Gobiesocidae). Cody's analysis was supportive of earlier, more general reports, including Drent (1965) who reported that over 70% of the diet of pigeon guillemot on Mandarte Island, B.C., was composed of blennies, flatfish, and sculpins, and Thoresen and Booth (1958), who listed Pacific sand lance, surf smelt (Hypomesus pretiosus), black prickleback (Xiphister atropurpureus), snake prickleback, and small flatfish as the principal prey fed to nestlings. Fourteen of 16 prey items consumed by pigeon guillemots in Yaquina Bay, Oregon, were flatfish; the other two were blennies (Scott 1973). The same study also mentioned one flatfish, eight planktonic crustaceans, and two crabs as the prey found in two adults collected offshore. Both fish and crustaceans (euphausiids, Thysanoessa inermis) were represented in the stomachs of pigeon guillemots collected in Alaskan waters between 1969 and 1976 by Sanger and Baird (1977).

Tufted Puffin

The only puffin which occurs in north Puget Sound and the Strait of Juan de Fuca and which plays any significant role in the food web is the tufted puffin (Lunda cirrhata). It is particularly abundant along Washington's northwest coast where it nests in colonies on the larger stacks and islands such as Carroll Island, Alexander Island, and Cake Rock (Cody 1973). One population estimate for the outer coast region was 7,343 nesting pairs (Manuwal 1977). Tufted puffin do not, however, nest in abundance inside the Strait of Juan de Fuca, as Protection Island which has the largest breeding colony in the region has only 25 to 30 nesting pairs (Manuwal 1977).

Cody's (1973) comparative study of the alcids indicated that primary prey delivered to nestlings by adult birds were, in decreasing order of importance, Pacific sand lance, northern anchovy, rockfish, and smelt. Sealy (1973) also listed Pacific sand lance as the major prey in June delivered by nesting adults. Manuwal (1977), however, did not identify Pacific sand lance as an important prey, rather smelt (Hypomesus?), Pacific herring, and northern anchovy. Manuwal (1977) and Bent (1929) also suggested that feeding adults have a broader prey spectrum that includes crustaceans, mussels, sea urchins, surf smelt, Pacific sardine (Sardinops sagax), Pacific herring, seaperch (Embiotocidae), Pacific sand lance, northern anchovy, and rockfish.

Amaral (1977) and Manuwal and Boersma (1977) reported 94.5% of the prey delivered (89.5% freq. occur.) to tufted puffin chicks on the Barren Islands, Alaska, was capelin; prowfish (Zaprora silensus) and squid also occurred but were insignificant. Sanger and Baird (1977), however, noted that fish and squid occurred approximately equally in their collections of tufted puffin in Alaskan waters between 1969 and 1976; Pacific sand lance was the only fish species identified from the stomach contents. Sanger, et al. (1977), listed capelin, Pacific sand lance, walleye pollock, and invertebrates as the principal prey of tufted puffin in the Kodiak Island area. Cod and capelin composed all of the prey of tufted puffin sampled by Hunt (1977) on St. Paul Island in the Pribilofs in 1976, but a year earlier the diet had been volumetrically dominated by unidentified crabs.

Rhinoceros Auklet

More than 11,000 breeding pairs of rhinocerus auklets were estimated along the outer coast, principally at Destruction Island, while 9,800 pairs were estimated for the San Juan Island and Strait of Juan de Fuca region, these breeding mainly at Protection Island (9,200) and Smith Island (600) (Manuwal 1977). As one of the most abundant seabirds occurring in the Strait of Juan de Fuca and the outer northwest Washington coast, rhinoceros auklets of this region have been studied extensively over the past few years, especially their diet (Richardson 1961; Cody 1973; Leschner 1976; Manuwal 1977; Wilson 1977). In most cases, these data were collected for breeding adults collecting food for nestlings, mainly on Destruction and Protection islands.

Richardson's (1961) documentation of prey delivered to nestlings on Protection Island listed 4-6 inch long Pacific sand lance as the main prey item, the only other fish being a surf smelt. The bill loads averaged 6.4 Pacific sand lance (ranging from 1 to 13 fish) and included extremely fresh fish, suggesting feeding grounds within 10 miles of Protection Island.

Annual variation was most obvious in the data obtained by Leschner (1976) from Destruction Island. Northern anchovy accounted for 56.0%, Pacific herring, 20.8%, and surf smelt, 15.3%, of the prey delivered to nestlings in 1974. In 1975, night smelt (Spirinchus starksi) and Pacific sand lance predominated (31.9% and 31.7%, respectively), followed by northern anchovy (26.8%). Species composition also varied considerably over the nesting period.

The comprehensive study by Wilson (1977) indicated that Pacific sand lance and Pacific herring were the most important prey of rhinoceros auklets nesting on Protection Island in 1975 and 1976, composing 90.6% of the total weight of 1,198 prey items over that time. Juveniles of all four species of Pacific salmon, adult northern anchovy and surf smelt, juvenile walleye pollock, and threespine stickleback occurred to a lesser extent. Prey species composition reported by Wilson varied less during the nesting period between 29 June and 29 August 1976 than the prey composition reported by Leschner (1976). In Wilson's study, juvenile salmonids declined slightly and Pacific herring increased slightly over that period. Peak utilization of Pacific sand lance occurred at the end of July, coinciding with the peak abundance of chicks being fed on the island. Wilson also documented an average daily consumption rate for nestling rhinoceros auklets of 54-55 g Pacific herring per day.

Manuwal's (1977) studies provide the most extensive data on rhinoceros auklet prey items and quantities. Although there was some annual variation between the two years sampled, prey delivered to nestlings on Protection Island were mostly Pacific sand lance and herring in terms of both numbers and biomass, augmented by juvenile salmon and several other neritic fishes (Table C-3). This prey spectrum was quite dissimilar to the spectrum at Destruction Island on the outer coast, where northern anchovy and night smelt were more important, and where annual variation in prey composition was more pronounced. Prey composition based on weight also shifted slightly over the nesting period (nine weeks) at Protection Island. Juvenile salmon were more important in the first four weeks, whereas Pacific herring gradually increased in importance through the nesting period. The average number of fish delivered to chicks on Protection Island was similar during the two years (5.62 in 1975, 5.65 in 1976) but the average weights of the loads were not similar (32.28 g in 1975, 29.52 in 1976) and the patterns over time were also dissimilar.

Outside the north Puget Sound and Strait of Juan de Fuca area, euphausiids appeared to be more important in the diet of adult rhinoceros auklets and their nestlings (Grinnel 1899; Linton 1908; Kozlova 1957; Komaki 1967). Pacific sand lance, however, dominated the stomach contents of four rhinoceros auklets collected in Alaskan waters (Sanger and Baird 1977).

Table C-3. Percent composition of numbers of prey delivered to rhinoceros auklet nestlings on Protection Island (from Munuwal 1977).

	1975		1976	
Prey	% Number	% Weight	% Number	% Weight
Pacific sand lance	82.78	70.60	74.36	63.76
Pacific herring	14.44	26.02	20.53	25.72
Chinook salmon, juv.	0.56	1.55	1.08	3.01
Pink salmon, juv.	0	0	2.26	3.50
Chum salmon, juv.	1.11	0.87	0	0
Coho salmon, juv.	0	0	0.10	0.19
Northern anchovy	0.56	0.77	0.79	2.09
Surf smelt	0	0	0.39	1.43
Walleye pollock	0	0	0.39	0.13
Threespine stickleback	0.56	0.19	0	0
Squid (unidentified)	0	0	0.10	0.17

Cassin's Auklet

Although common offshore, Cassin's auklets are not frequently encountered nearshore, but they have been reported to breed on Carroll and Alexander islands and on Cake Rock on the outer coast (Cody 1973). According to Cody, Cassin's auklet is the only alcid in Washington that forages on plankton at long distances. The plankton is regurgitated as a soup to the nestlings. Thoreson (1964) and Manuwal (1974) documented euphausiids (Thysanoessa spinifera), amphipods (Phromema sp.), and squid as the main components of their diet off the coast of California. Sanger and Baird (1977) listed only unidentified crustaceans in the stomach contents of five Cassin's auklets collected in Alaskan waters.

Ancient Murrelet

Although neither Salo (1975) nor Manuwal (1977) includes ancient murrelets in his survey, they appear, although infrequently, in the northern reaches of Puget Sound during migration from their breeding sites in Alaska and British Columbia and many may overwinter in the region (Sealy 1976). The 1976 Audubon Christmas bird count recorded 377 at Victoria, B.C., and incidental sightings at Pender Islands and Vancouver, B.C., and Bellingham, Washington (Heilbrum, et al., 1977).

Sealy's (1972) detailed comparison of the feeding ecology of the marbled murrelet and the ancient murrelet during the breeding season in the Queen Charlotte Islands, B.C., illustrated that adult ancient murrelets prey specifically on euphausiids (Euphausia pacifica, Thysanoessa spinifera), which composed 92.4% of the total prey abundance, while fish (Pacific sand lance and shiner perch) made up only 7.2%. Subadult birds, however, fed more upon fish, primarily Pacific sand lance 30-60 mm in length, which accounted for 45.7% of the total prey abundance vs. 55.3% for invertebrates. Juvenile ancient murrelets were essentially piscivorous (98.3%). The euphausiid E. pacifica prevailed in the diet in March and April before it was supplanted by T. spinifera; Pacific sand lance and shiner perch occurred during the period between mid-June and mid-July. Sealy (1973) also noted that ancient murrelets often fed in conjunction with black-legged kittiwakes and glaucous-winged gulls, which were feeding on similar prey organisms at the surface. The results of Sanger and Baird's (1977) examination of ancient murrelets in Alaskan waters were generally similar, the euphausiid Thysanoessa inermis being the principal prey of adult birds.

Marbled Murrelet

Marbled murrelets are an abundant summer bird along the Pacific Northwest coast (Drent and Guiguet 1961) and are presumed to nest inland on large rivers (Hoh and Quileute) of the Olympic Peninsula (Cody 1973).

Compared with the prey spectrum of adult ancient murrelets, that of adult and subadult marbled murrelets is much more oriented toward fish. Sealy (1972) documented that small (less than 60 mm in length) Pacific sand lance provided 61.8% of the total prey abundance of prey organisms for marbled murrelets in the Queen Charlotte Islands, B.C.; shiner perch, rockfish, osmerids (smelt, capelin, eulachon), and prickleback were other important fishes. Euphausiids (Thysanoessa spinifera) larger than 12 mm formed the majority of the invertebrates consumed, which overall contributed only 26.8% of the total prey abundance, and occurred only early (mid-April to late June) in the breeding season. Shiner perch and osmerids appeared in the diet primarily in the latter half of the breeding season (early July to mid-August). Sealy (1973) also found marbled murrelets feeding upon T. spinifera in conjunction with glaucous-winged gulls.

Manuwal and Boersma (1977) also listed fish (unidentified) as the main constituent (67% abundance) of the food of marbled murrelets collected in the Gulf of Alaska and the southeastern Bering Sea. Both fish (67% freq. occur.) and unidentified crustaceans (33%) occurred in marbled murrelets collected in Alaska' south-central waters (Sanger and Baird 1977).

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APPENDIX D. MARINE MAMMALS

D-1. Cetaceans

Scheffer and Slipp (1948) recorded 20 species of cetaceans (whales, dolphins, and porpoises) in the marine waters of Washington State; Pike and MacAskie (1968) listed 21 from British Columbia (Table D1).* These comprehensive accounts, however, were based principally upon records of the coastal whaling stations** and of strandings, rather than upon systematic survey observations with estimates of abundance. As a result they do not necessarily reflect whale populations of today, many of which (sperm and humpback whales) have been seriously depleted by overharvesting; only gray whales have recovered to their estimated original abundance. In addition, only a few of the cited species were ever common to the enclosed waters of Puget Sound, the Strait of Georgia, and the inner Strait of Juan de Fuca, though many were encountered during aboriginal whaling activities by the Makah Indians, who were located on the western end of the Strait of Juan de Fuca. Of the modern occurrences of cetaceans in the region's inland waters, only two cetaceans--orca (killer whale) and harbor porpoise--can still be considered abundant, and four--Pacific white-sided dolphin, Dall porpoise, gray whale, and Minke whale--are still relatively common. The following species accounts consider all cetaceans reported in or adjacent to the Strait of Juan de Fuca and northern Puget Sound, but the preceding food web section discusses only the six species which now occur in the region.

All the cetaceans documented for the region have been categorized according to six functional feeding groups (Table D-2). Of the common or abundant species, gray and Minke whales were determined to be obligate planktivores and the Pacific white-sided dolphin and the Dall porpoise, facultative piscivores in pelagic habitats; in nearshore habitats, the Pacific harbor porpoise has been classified as an obligate piscivore while the orca or killer whale sits at the peak of the marine food web as a facultative carnivore.

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*Nomenclature has been standardized according to Rice (1977).

**Statistics came mostly from one station operating at Bay City, Washington, from 1911 to 1925 and another at Coal Harbour on Vancouver Island, British Columbia, from 1948 through 1959 and 1962 through 1967.

Table D-1. Cetaceans occurring in Washington State and British Columbia. A = abundant, C = common, NC = not common, R = rare, c = coastal only, i = inshore Puget Sound and Strait of Juan de Fuca.

Order Cetacean--whales and dolphins	Washington State (Scheffer and Slipp 1948)	British Columbia (Pike and MacAskie 1969)	Reported habitat
Suborder Odontoceti--toothed whales and dolphins			
Family Ziphiidae--beaked whales			
Berardius bairdii Stejneger, Baird's beaked whale	NC	C	i
Mesoplodon stejnegeri True, Stejneger beaked whale	R	R	c
M. carlhubbsi Moore, Hubbs' beaked whale		R	c
Ziphius cavirostris Cuvier, Cuvier's beaked whale		R	i
Family Physeteridae--sperm whales			
Physeter catodon Linnaeus, sperm whale	C	C	c
Kogia breviceps Blainville, pygmy sperm whale		NC	i
Family Delphinidae--ocean dolphins			
Stenella sp., spotted dolphin		R	i
Delphinus delphis Linnaeus, Pacific common dolphin	R	R	i
Lissodelphis borealis Peale, northern right-whale dolphin	R	R	c
Lagenorhynchus obliguidens Gill, Pacific white-sided dolphin	C	C	i
Orcinus orca Linnaeus, killer whale or orca	A	A	i
Grampus griseus Cuvier, gray grampus or Risso's dolphin		R	i
Pseudorca crassidens Owen, false killer whale	R		i
Globicephala macrorhyncha, shortfin pilot whale	NC	NC	i
Phocoena phocoena Linnaeus, Pacific harbor porpoise	A	A	i
Phocoenoides dalli True, Dall porpoise	C	C	i
Family Monodontidae--Arctic dolphins			
Delphinapterus leucas, beluga whale	R		c

Table D-1. Cetaceans occurring in Washington State and British Columbia. A = abundant, C = common, NC = not common, R = rare, c = coastal only, i = inshore Puget Sound and Strait of Juan de Fuca - cont'd

Order Cetacean--whales and dolphins	Washington State (Scheffer and Slipp 1948)	British Columbia (Pike and MacAskie 1969)	Reported habitat
Suborder Mysticeti--whalebone whales			
Family Eschrichtiidae--gray whales			
Eschrichtius robustus Lilljeborg, gray whale	C	C	i
Family Balaenopteridae--furrow-throated whales			
Balaenoptera physalus Linnaeus, fin or finback whale	C	C	i
B. borealis Lesson, sei whale	C	C	c
B. acutorostrata Lacepede, little piked whale, minke whale	NC	NC	i
B. musculus Linnaeus, blue whale		NC	c
Megaptera novaeangliae Borowski, humpback whale	NC	NC	i
Family Balenidae--smooth-throated whales			
Balaena glacialis Muller, northern or black right whale	R	R	c

Table D-2. Functional feeding groups and representative prey taxa of marine mammals known or suspected to occur in north Puget Sound and the Strait of Juan de Fuca. Species common or abundant in the region are underlined. Species involving questionable sightings or extremely rare species are in parentheses.

Habitat	Feeding group	Predator species	Representative prey taxa
Pelagic	Obligate planktivore	Gray whale* Finback whale Sei whale Minke whale Blue whale North Pacific right whale	Calanoid copepods (*Calanus* sp.) Euphausiids (*Euphausia pacifica*, *Thysanoessa* sp.) Crab zoea (*Pachycheles rudis*, *Cancer* sp.) Squid (*Ommastrephes* sp.) Pacific saury (*Coloabis saira*) Northern anchovy (*Engraulis mordax*) Walleye pollock (*Theragra chalcogramma*) Pacific sand lance (*Ammodytes hexapterus*)
	Facultative (macro-)planktivore	Humpback whale (Shortfin pilot whale?)	Squid (Gonatidae, Histioteuthidae, Ommastrephidae, Onychoteuthidae) Rockfish (*Sebastes* sp.) Lingcod (*Ophiodon elongatus*) Skate (Rajiidae) Lancetfish (*Alepisaurus* sp.) Shark (Squaliformes) Surf smelt(*Hypomesus pretiosus*) Atka mackerel (*Pleurogrammus monopterygius*) Pacific sardine (*Sardinops sagax*) Euphausiids (*E. pacifica*, *Thysanoessa* sp.)
	Obligate piscivore	Gray grampus dolphin? False killer whale Northern fur seal Northern elephant seal (Beluga whale)	Capelin (*Mallotus villosus*) Pacific herring (*Clupea harengus pallasi*) Pacific sardine (*S. sagax*) Salmon (*Oncorhynchus* sp.) Northern anchovy (*E. mordax*) Walleye pollock (*T. chalcogramma)* Eulachon (*Thaleichthys pacificus*) Pacific sand lance (*A. hexapterus*)

Table D-2, cont'd

Habitat	Feeding group	Predator species	Representative prey taxa
			Squid (*Loligo opalescens*, *Gonatus* sp., *Ommastrephes* sp., *Onychoteuthis* sp.)
	Facultative piscivore	Baird's beaked whale Stejneger beaked whale and other *Mesoplodon* sp. (Cuvier's beaked whale) (Spotted dolphin, *Stenella* sp.) (Pacific common dolphin) Pacific white-sided dolphin Northern right-whale dolphin? Dall porpoise Pygmy sperm whale	Lanternfish (Myctophidae, *Diaphus* sp.) Pacific hake (*Merluccius productus*) Northern anchovy (*E. mordax*) Pacific saury (*C. saira*) Squid (*Gonatus* sp., *Onychoteuthis* sp., *L. opalescens*) Shrimp (*Bentheogennema borealis*, *Pasiphaea pacifica*, *Pandalus* sp.) Pacific herring (*C. harengus pallasi*) Capelin (*M. villosus*) Juv. rockfish (*Sebastes* sp.) Salmon (*Oncorhynchus* sp.) Octopus (*Octopus* sp.)
Nearshore	Obligate piscivore	Harbor porpoise Northern sea lion California sea lion Pacific harbor seal	Pacific herring (*C. harengus pallasi*) Pacific sand lance (*A. hexapterus*) Walleye pollock (*T. chalcogramma*) Salmon (*Oncorhynchus* sp.) Starry flounder (*Platichthys stellatus*) Pacific tomcod (*Microgadus pacificus*) Rockfish (*Sebastes* sp.) Skate (Rajiidae) Pacific cod (*Gadus macrocephalus*) Pacific hake (*M. productus*) Spiny dogfish (*Squalus acanthias*) Plainfin midshipman (*Porichthys notatus*) Greenling (Hexagrammidae) Shiner perch (*Cymatogaster aggregata*)

Table D-2, cont'd

Habitat	Feeding group	Predator species	Representative prey taxa
			Pacific staghorn sculpin (*Leptocottus armatus*) Eelpout (Zoarcidae) Blackfin sculpin (*Malacocottus kincaidi*) Shrimp Crabs (*Cancer* sp.) Octopus (*Octopus* sp.)
	Facultative carnivore	Orca (killer whale)	California sea lion (*Zalophus californianus*) Northern sea lion (*Eumetopias jubatus*) Harbor seal (*Phoca vitulina*) Elephant seal (*Mirounga californianus*) Harbor porpoise (*Phocoena phocoena*) Dall porpoise (*Phocoenoides dalli*) Minke whale (*Balaenoptera acutorostrata*) Nursing calves of humpback (*Megaptera novaeangliae*), finback (*Balaenoptera physalus*), and gray whales (*Eschrichtius robustus*) Lingcod (*O. elongatus*) Salmon (*Oncorhynchus* sp.) Steelhead trout (*Salmo gairdneri*) Pacific halibut (*Hippoglossus stenolepis*) Pacific herring (*C. harengus pallasi*)?

*On feeding grounds outside the north Puget Sound - Strait of Juan de Fuca region, gray whales feed on benthic and epibenthic organisms.

?--denotes subjective assignment of predator species to feeding group in absence of food habits data.

Species Accounts

Baird's Beaked Whale

Looking much like a small sperm whale (10-15 m long at maturity), Baird's beaked whale appears to occur principally along the coast, peak occurrences being in the fall. Six whales were reported in early October 1976, 75 km offshore of Westport, Washington, by Wahl (1977). Of thirteen stomachs examined from the Coal Harbour station between 1950 and 1958, three were empty. Squid and rockfish (Sebastes spp.) bones appeared in seven stomachs and skate egg cases were found in the stomach contents of two.

Stejneger Beaked Whale and Other Mesoplodon sp.

Another group of beaked whales includes three species of Mesoplodon, of which M. stejnegeri appears to be the prominent species. They appear typically along the coast, although an early record by Scammon (1874) indicated a large number may have occurred in Port Townsend Bay (Scheffer and Slipp 1948). There is no recorded account of stomach contents of any of these species. We assume they would feed similarly to the other beaked whales, i.e., basically upon squid and fishes.

Cuvier's Beaked Whale

Although no confirmed records of Cuvier's beaked whale originate from Washington, there have been a number of records from the west coast of Vancover Island and the Queen Charlotte Island area. Little stomach contents information is presently available. Recently, a Cuvier's beaked whale, 4.3 m in length, washed ashore on the north side of Nizki Island in the western Aleutians, and the stomach was examined and reported to contain squid remains (R.M. Mayer, Fish. Res. Inst., personal communication, 1979).

Sperm Whale

Although now seldom reported off the coast of Washington, the largest of the toothed whales (15-20 m at maturity) were third in abundance in the catch at Bay City, Washington, stations, 1913-1915 and 1918-1919 (Scheffer and Slipp 1948), and composed almost 80% of the whales taken at Queen Charlotte Islands' whaling stations between 1933 and 1943, and 32% of those taken at Coal Harbour between 1948 and 1959 (Pike and MacAskie 1968). Sperm whales therefore may have been a predominant species before coastal whaling off Washington and southern British Columbia and present high seas whaling reduced their numbers. They appeared from late spring through early fall in large harem schools in the open ocean up to 200 miles from the west coast of British Columbia (Pike and MacAskie 1968). This concentration was apparently a feeding aggregation, as most stomachs contained food organisms, including squid (*Moroteuthis robusta* and *Gonatus* sp.), hagfish (*Eptatretus stouti*), and rockfish. Octopi, codfish (Gadidae), and a lamprey (Petromyzontidae) constituted incidental prey items (Robbins, et al., 1937).

Small to moderate sized cephalopod molluscs (squid and octopus) appeared to be the prevalent prey items of sperm whales on most localities including the western Gulf of Alaska (Thompson 1940; Kawakami 1976), the Bering Sea (Okutani and Nemoto 1964), California (Fiscus and Rice 1974, Japan (Okutani, et al., 1976), the Kurile Islands (Bethesheva and Akimushkin 1955), New Zealand (Gaskin and Cawthorn 1967), Spain (Clarke and MacLeod 1974), and Northwest Africa (Clarke 1962). Taxonomic composition of the squids varied according to the geographic region, but the family Gonatidae composed more than half of the squid prey reported for the North Pacific. Okutani, et al. (1976), identified 15 species belonging to 9 families where species of the families Histioteuthidae, Ommastrephidae, and Onychoteuthidae numerically predominated. The so-called giant squid, *Architeuthis* sp. and *Moroteuthis robusta*, did not occur frequently but contributed high biomass proportions when they did occur.

Fish appeared less frequently than squid in almost all circumstances but often contributed considerably to the total prey biomass. Gaskin and Cawthorn (1967) documented a 1.7:1 ratio of squid to fish by weight. All of the 14 sperm whale stomachs examined at Port Hobron in 1937 and 8 of the 13 from Akutan in 1938 had cephalopod remains. Fish (lingcod, *Ophiodon elongatus*), rockfish, skates (family Rajiidae), and their egg cases) and hermit crabs (Paguridae) were secondary prey items (Thompson 1940).

Backus (1966) described the contents of one sperm whale from the Azores as containing "10 or 12 photophore-bearing cephalopods, each about 1 m in total length, 2 lancetfish (*Alepisaurus* sp.), each about 1 m long, and the partial remains of a large shark" (probably *Cetorhinus maximus*).

Spotted Dolphins

No specimen records nor stomach contents of spotted dolphins (*Stenella styx*, *S. euphrosyne*, and *S. caeruleoalba*) have been examined from the northern Washington or southeastern British Columbia coasts. Wahl (1977) reported one sighting of *S. caeruleoalba*, 72 km northwest of Westport in late September 1976.

Miyazaki, et al. (1973), provided detailed stomach contents analyses of 27 specimens of *S. caeruleoalba* from Sagami Bay, Japan. An average of 53.6 ± 43.6 (± 1 s.d.) prey organisms comprising 7.6 ± 3.5 species was contained in each stomach, weighing an average of 1,074 ± 418 g. Fish numerically dominated the stomach contents at 59% of the total prey abundance. Lanternfishes were the prevalent group, especially *Diaphus* sp., accounting for 64% of all identified fishes. The estimated body lengths of consumed fishes ranged from 60 to 300 mm. Shrimp, especially *Bentheogennema borealis*, were also common prey components, followed by squid. All prey species were pelagic or epipelagic. Since the coastal environments of central Japan and northern Washington and southern British Columbia are similar, the food habits of this genus of dolphin may also be similar.

Pacific Common Dolphin

One specimen of this species, relatively rare in the region, recovered at Victoria, B.C., was not examined for stomach contents. Fiscus and Niggol (1965) reported the stomach contents of four animals from central California. Fish--Myctophidae, northern anchovy (*Engraulis mordax*), Pacific saury (*Cololabis saira*)--and squid (*Gonatus* sp., *Onychoteuthis* sp., *Loligo opalescens*) were the predominant prey items.

Northern Right-Whale Dolphin

One right whale found stranded on a southwestern Washington coastal beach had one squid beak in its stomach (Scheffer and Slipp 1948). About 20 individuals were observed by Wahl (1977) in association with gray grampus dolphins in October 1974, 85 km west of Westport.

Pacific White-Sided Dolphin

Pike and MacAskie (1969) listed 32 sightings of Pacific white-sided dolphins from British Columbia and northern Washington which suggested an inshore movement in winter and an offshore movement in summer. The northernmost observation made by Fiscus and Niggol (1965) was off Point Grenville; they reported few Pacific white-sided dolphins inside the 100-fm and few outside the 1,000-fm curve. Wahl (1977) included one report of 25-30 Pacific white-sided dolphins observed 72 km northwest of Westport in late September 1976. Extremely large pods of 1,000-2,000 animals have been reported in the Gulf of Alaska (Pike 1959; Fiscus, et al., 1977); 55 other sightings have been reported between 1958 and 1975 (Fiscus, et al., 1977).

Few stomach samples have been examined in the northeastern Pacific region. Five from California coastal waters reported in Fiscus and Niggol (1977) had consumed fish (northern anchovy, 45-95%, and Pacific hake, *Merluccius productus*, 5-10%) and squid (*Gonatus* sp.). Another specimen from California was reported to have fed upon squid (Scheffer 1950b) while another from that area had consumed Pacific sardine (*Sardinops sagax*) (Higgins 1919).

Lanternfishes were the main fish (77% of total stomach contents volume) of the prey consumed by 13 Pacific white-sided dolphins examined by Wilke, et al. (1953); anchovy, *Engraulis japonica*, and chub mackerel, *Scomber japonicus*, were the other prey fishes. Squid beaks and eye lenses, probably from *Watasenia scintillans*, composed only 7% of the stomach contents volume.

Orca (Killer Whale)

Undoubtedly the most ubiquitous toothed whale in north Puget Sound and the Strait of Juan de Fuca is the orca. As of 1977, approximately 115 whales occurred in this area, of which 65-70 could be considered residents (composing four distinct pods designated J, K, L 8, and L 10) and the remainder transients (composing seven pods, A5, E, G, M, N, O, and Q) (Bigg , et al., 1976). Recent sightings suggest that the resident pods may now comprise 75-80 individuals (Balcomb 1978; K. Balcomb and R. Osborne, pers. comm.).

There was no distinct pattern to their distribution and movements (M.S. Bigg, Pac. Biol. Sta., pers. comm.), which appeared to be related directly to feeding or the search for food (Balcomb and Goebel 1976). Only J pod appeared to be completely residential in Puget Sound, the Strait of Georgia, and eastern Strait of Juan de Fuca, having a range of about 210 nautical miles. The other three pods apparently resided in the region 8-9 months of the year, entering and leaving through the Strait of Juan de Fuca; there is no information on their movement along the outer coast. The transient pods occurred infrequently, moving into and out of the northern Strait of Georgia from the north, and have never been seen inside Puget Sound proper. Several aggregations of 3 to 17 animals were sighted, 25-100 km off Westport by Wahl (1977) between May and September.

Scheffer and Slipp (1948) summarized orca food habits and feeding behavior known to that time. A diverse array of marine mammals, sea birds, fishes, and cephalopod molluscs were the principal prey taxa described. Smaller individuals and nursing calves of humpback (*Megaptera novaeangliae*), finback (*Balaenoptera physalus*), and gray (*Eschrichtius robustus*) whales, harbor porpoise (*Phocoena phocoena*), hair seal, black brant (*Branta nigricans*), greenling (Hexagrammidae), lingcod, salmon (*Oncorhynchus* sp.), and squid were the specific organisms itemized.

Nishiwaki and Handa (1958) were the first to evaluate orca food habits on a large scale. Their analysis of the stomach contents of 364 orcas from the coast of Japan indicated that the whales fed mostly on fishes and cephalopods, but also on large numbers of cetaceans and pinnipeds.

Detailed information on orca food habits was assembled by Rice (1968). He summarized the stomach contents of ten orcas collected in offshore waters of the eastern North Pacific between Kodiak Island, Alaska, and San Miguel Island, California. Eight of the ten stomachs examined contained marine mammal remains, specifically California sea lion (*Zalophus californianus*), northern sea lion (*Eumetopias jubatus*), elephant seal (*Mirounga anguisirostris*), harbor porpoise, Dall porpoise (*Phocoenoides dalli*), and minke whale (*Balaeroptera acutorostrata*), which made up over 75% of the total prey. Three stomachs contained fish, including Pacific halibut (*Hippoglossus stenolepis*), opah (*Lampris regius*), and carcharinid sharks. Only one specimen contained cephalopod remains. Martinez and Klinghammer (1969) generally itemized orca prey organisms, which included 10 species of cetaceans, 8 pinnipeds, 11 teleost fishes, 6 other vertebrates, and 3 elasmobranch fishes. One specimen from California examined by Fiscus and Niggol (1965) was presumed to have eaten one California sea lion, one cetacean, and as many as four elephant seals.

Other recorded prey organisms of orcas have included northern fur seal (*Callorhinus ursinus*) in the western North Pacific (Bychkov 1967); bearded seal (*Evignathus barbatus*) and walrus (*Odobenus rosmarus*) in the Bering Sea (Zenkovich 1938); eagle ray (*Myliobatis* sp.) off Brazil (Costello 1977); leatherback sea turtle (*Dermochelys coriacea*) in the Lesser Antilles (Caldwell and Caldwell 1969); and minke whale along the northwest coast of Vancouver Island, B.C. (Hancock 1965).

Recent observations of orca feeding activity and collections of prey remains made by Pacific Biological Station biologists off southeastern Vancouver Island identified chinook (*Oncorhynchus tshawytscha*), coho (*O. kisutch*), and sockeye salmon (*O. nerka*), and anadromous (steelhead) trout (*Salmo gairdneri*) as important food items in the region of concern (M. Bigg and G. Ellis, unpub. data).

Existing reports of orca food habits imply that pinnipeds and small cetaceansconstitute the preferred prey organisms and the staple element of the orca diet in most regions of the world. Rice (1968) has pointed out, however, that, "in Puget Sound, where the killer whale population is probably denser than anywhere else in the world,the marine mammal population (mostly harbor porpoise, Minke whale, Pacific harbor seal, and a few northern sea lions) does not appear large enough to provide a major proportion of the killer whale's diet. It is widely believed that runs of spawning salmon are a major food there during the summer, but no data are available to support this assumption." As supported by Bigg's recent evidence, salmon and abundant schooling forage fishes such as Pacific herring (*Clupea harengus pallasi*) and Pacific sand lance (*Ammodytes hexapterus*) may be the most stable trophic contribution to the orca's diet in northern Puget Sound and the Strait of Juan de Fuca, supplemented by such pinnipeds and small whales as they may encounter.

Feeding behavior may also vary from pod to pod. Balcomb and Goebel (1976) identified L pod as being more aggressive in its food habits than others; i.e., it was the only one observed to take marine mammals. The L pod typically frequented the waters on the west side of Vancouver Island and the Olympic Peninsula, venturing periodically into inland waters through the Strait of Juan de Fuca.

Gray Grampus or Risso's Dolphin

Stroud (1968) documents one of the few records of gray grampus dolphin in Washington. His description of a young male specimen which washed ashore at Makkaw Bay (northwest, exposed coast of Olympic Peninsula) included contents of the stomach, which, though the animal had been dead about a month, included 44 (55 g) identifiable squids. Seven taxa were represented; *Gonatus fabrici*, two other gonatids, and *Chiroteuthis verangi* were the most prominent forms but *Onychoteuthis banksi* and *Octopodoteuthis sicula* were also present. Several verified records and several credible sightings of gray grampus dolphin exist for British Columbia which is apparently the northern limit of its range (Guiguet and Pike 1965; Pike and MacAskie 1968); no food habits were determined, however. Wahl (1977) reported three sightings, one in October 1974 and two in September 1976, of gray grampus in groups of 40 to 60, often mixed with other species such as Pacific striped dolphin.

False Killer Whale

Scheffer and Slipp (1948) provided the only record of a false killer whale in Washington and British Columbia, an animal stranded near Olympia (south Puget Sound) in 1937. Its stomach contained some salmon remains.

Shortfin Pilot Whale

Although sightings of Pacific pilot whales have occurred frequently, especially in 1958 when there appeared to be a northward shift in distribution, there were but a few verified specimens in the Washington and British Columbia region (Pike and MacAskie 1968). They do not appear to move into the region's coastal waters before mid-April (Fiscus and Niggol 1965). Sighting data recently compiled by the Moclips Cetological Society's Orca Survey suggest that five to ten groups may frequent Puget Sound each year, principally in spring and summer (Rich Osborne, pers. comm.). No diet information was reported.

Harbor Porpoise

Considered the most frequently seen cetacean in Washington State by Scheffer and Slipp (1948), harbor porpoise range the breadth of Puget Sound and the Strait of Georgia, through the Strait of Juan de Fuca, and well offshore Washington and British Columbia. They were frequently sighted by Wahl (1977) close inshore of Westport and in Grays Harbor channel, usually in groups of one to five animals. They have been captured in nets set on the bottom as deep as 44 fm. When seen in Puget Sound they were often in groups of two to five, occasionally ten to twelve. The 1977 Orca Survey, conducted by the Moclips Cetological Society (Balcomb 1978) also reported seven sightings of harbor porpoise in the San Juan Islands; compilation of their total data, however, suggests that between 30 and 60 are seen each year in northern Puget Sound (Rich Osborne, pers. comm.).

Scheffer and Slipp (1948) concluded from the contents of four stomachs that, "the favorite foods of the harbor porpoise are probably fishes under a foot in length; of slender form and soft flesh; lacking stiff spines and armor; including types that commonly run in schools near, but not on, the bottom. Such speedy swimmers as the salmon and trout; bottom dwellers; heavily armed species like the rock-cod and sculpin, and invertebrates with the exception of the squid, are probably not important in the diet of the porpoise."

Five Pacific herring were found in the stomach of one female harbor porpoise examined at Port Townsend, Washington, in May 1950 (Wilke and Kenyon 1952).

Dall Porpoise

Despite the high abundance of Dall porpoise in Washington and British Columbia waters, second only to the harbor porpoise, few described specimens existed (Scheffer and Slipp 1948; Pike and MacAskie 1968). Dall porpoise appeared to be most abundant offshore and common in the Strait of Juan de Fuca, though seldom seen in either the Strait of Georgia or Puget Sound proper. Fiscus and Niggol (1977) observed Dall porpoise six times during April 1959, all within 50 km of shore. Sightings of Dall porpoise were made on 24 of the 34 cruises between July and October described by Wahl (1977), but sightings occurred on only 2 of 12 cruises between mid-April and mid-May. The majority of these observations were made more than 50 km offshore and were of groups of 3 to 6 porpoise. Dall porpoise generally travel in schools of 5 to 14 (usually 6) but are encountered inshore in groups of 30 to 100 in spring and fall. Eight sightings of Dall porpoise were reported in the 1977 Orca Survey (Balcomb 1978), principally along western Whidbey Island between Rosario Strait and Possession Point. More recent assessment of the survey data indicates that three to four groups, comprising 40 to 60 individuals,of Dall porpoise frequent Puget Sound (Rich Osborne, pers. comm.).

Pacific herring were the sole prey found in the stomachs of four Dall porpoise taken in Queen Charlotte Sound, B.C., by Cowan (1944). The stomachs of the Dall porpoise collected in 1937 between Sauk Inlet and Port Angeles along the Strait of Juan de Fuca contained fish and squid beaks and unidentified "eyes" (Scheffer and Slipp 1948). Of five specimens collected offshore Washington and British Columbia between 1957 and 1959, the stomachs of two were empty, two had "mostly squids," and one had "mostly herring." Stomach contents of nine Dall porpoise collected off the California and Washington coasts between 1964 and 1972 (Stroud et al. 1964-72) contained 4 species of pelagic fish, one flounder and six species of squid. Fiscus and Niggol (1965) examined the stomach contents of five specimens collected off northern California; one stomach was empty, the other four contained only remains of squid.

The stomach contents of 25 Dall porpoise from Monterey Bay were examined by Loeb (1972). She found that hake (*Merluccius productus*), juvenile rockfish, and the squid *Loligo opalescens* were the prevalent prey between May and December, and northern anchovy and Pacific herring became important in winter. During the period between October and April other fish species became important: Myctophids (including predominantly *Tarletonbeania crenularis*), night smelt (*Spirinchus starksi*), Pacific sanddab (*Citharichthys sordidus*), spotted cusk-eel (*Otophidium taylori*), pompano (*Petrilus simillimus*), juvenile sablefish (*Anoplopoma fimbria*), California smoothtongue (*Bathylagus stilbius*), pinpoint lampfish (*Lampanyctus regalis*), snailfish (*Liparis* sp.), eelpouts (Zoarcidae), grenadiers (Macrouridae), and eels. Pelagic cephalopods found in the stomachs included the squids *Abriolepsis felis*, *Gonatus* sp., and *Onychoteuthis boreali-japonicus*, and the octopus *Octopus bimaculatus*.

Capelin (*Mallotus villosus*) were the only prey found in the stomachs of two porpoise from the Gulf of Alaska examined by Scheffer (1953). Squid predominated in the stomach contents of 148 Dall porpoise from the Bering Sea and North Pacific examined by Mizue, et al. (1966); fish, including sockeye salmon, and shrimp were secondary components of the diet.

Ninety-eight percent of the total volume of the stomach contents of four Dall porpoises collected off Japan by Wilke et al. (1953) was squid, predominantly *Ommastrephes sloani pacificus*; a gadid fish, *Laemonema morosum*, composed the remainder of the contents. Lanternfishes (predominantly *Notoscopelus* sp. and *Tarletonbeania taylori* as well as *Diaphus* sp., *Lampanyctus* sp., *Myctophum* sp. and other unidentified myctophid species) and a fish species of the family Sudidae (*Paralepis* sp.) were the principal prey of seven Dall porpoise described by Wilke and Nicholson (1958); squids (including *Watasenia scintillans* and *Ommastrephes sloani pacificus*), though frequently fed upon, did not provide a high percentage of the stomach contents volume.

Beluga Whale

Scheffer and Slipp (1948) included a 1940 report of a white or beluga whale observed in south-central Puget Sound. This was an extremely rare occurrence for a whale which was previously not seen south of Cook Inlet, Alaska.

Belugas apparently have a broad prey spectrum. Kleinberg, et al. (1964), reported prey including arctic cod (Boregadus saida), capelin, salmon, flatfish (Pleuronectidae), herring, and crustaceans. Johnson, et al. (1966), examined the stomachs of two belugas taken in the Cape Thompson region of Alaska and described the contents as arctic cod and at least three species of shrimp.

Pygmy Sperm Whale

Very few specimens of this species were reported from the Pacific coast of North America, though one from the central coast of Washington was examined in 1942 (Scheffer and Slipp 1948). Although it had been dead for two weeks, its stomach still contained evidence of 15 squid, at least 10 fish (including Pacific sandfish, Trichodon trichodon), crab, and shrimp (including Pasiphaea pacifica, Pandalus borealis?, and Pandalopsis dispar?).

Gray Whale

Gray whales pass close inshore through Washington and British Columbia coastal waters during their migration between their calving grounds along southern California and northern Mexico and the summer feeding grounds in the Bering Sea. They usually appear during their northward migration between February and May and in December and January during their southward migration (Pike and MacAskie 1968), traveling individually or in groups of two, three, or four. Wahl's (1977) four sightings all occurred in May and were typically close inshore. It was primarily during the northward migration in spring that the Indian whalers of the Pacific Northwest concentrated on the gray whale, highly susceptible to their harvest because of its small size, moderate speed, and tendency to pass close inshore (Scammon 1974; Scheffer and Slipp 1948). They generally cross the mouth of the Strait of Juan de Fuca in a line between Cape Flattery and Pachena Point, Vancouver Island (Hatler and Darling 1974; Hart 1977), or Carmanah and Cape Beale (Pike 1962). The incidence of gray whales venturing inside the Strait of Juan de Fuca is not high. One was reported at Point Defiance, in south-central Puget Sound, in about 1938, and recently a young calf was discovered floating dead in Possession Sound (Seattle P-I, June 21, 1978), and one beached near Neah Bay in August 1978. Included in Balcomb's (1978) 1977 Orca Survey were eight sightings of gray whales, two in the Port Angeles vicinity, two around Bremerton, and four in southern Puget Sound. In general, 20 individuals may be assumed to frequent Washington's inland waters annually (Rich Osborne, pers. comm.).

Scammon (1874), Pike (1962), and Rice and Wolman (1967, 1971) maintain that in general gray whales do not feed significantly along the southern section of their migration route; only one of the 84 stomachs examined by Rice and Wolman (1967) contained prey organisms, zoea of the crab Pachycheles rudis. Wilke and Fiscus (1961), Hewell and Huey (1930), Rau and Schevill (1974, citing Ken Balcomb, pers. comm.), and Hart (1977), however, have provided indications of feeding activity or significant stomach contents for some gray whales during the migration along the Pacific Northwest coast. Planktonic euphausiids (Euphausia pacifica) and nektonic fishes (rainbow smelt, Osmerus mordax?, northern anchovy)were the prevalent prey in these instances. The stomach of the dead calf from Possession Sound was reported to contain crab zoea (Bob Everitt, NOAA, pers. comm.).

On their usual feeding grounds in the Bering and Chukchi seas (Pike 1962), benthic and epibenthic organisms are the prevalent food, specifically gammarid amphipods but also other epibenthic crustaceans such as mysids, cumaceans, and isopods (Pike 1962; Rice and Wolman 1967, 1971; Tomilin 1957; Zimushko and Lenskaya 1970). Wilke and Fiscus (1961) described the feeding whales making large muddy blotches in the water as they came to the surface to blow, implying that, "in feeding along the bottom the whales gathered mud along with food and were expelling it through their baleen as they rose to the surface." Tomilin (1957) supposed that the whales fed by scooping and plowing their mouths into the bottom, but Ray and Schevill (1974), from observations of a captive juvenile gray whale, documented a bottom-sweeping feeding sequence wherein "the whale rolls over far enough so that the cheek is about parallel with the bottom, and the lip is opened as the tongue, pressing against the palate, pushes the gular region away so that it expands, producing an inflow which brings in the epibenthic food. Then the tongue relaxes and the gular musculature tightens, reducing the size of the mouth cavity and expelling water; the food is trapped in the baleen fringes. We do not know exactly what happens next; perhaps a slight renewed suction of water removes the food from baleen fringes, and swallowing presumably follows." This behavior, if real, would explain the asymmetric distribution of barnacles along the head, producing predominantly "right-sided" (feeding on left side) animals (Kasuya and Rice 1970).

Finback (Fin) Whale

Historically, fin whales were the first or second most abundant whale of the Pacific Northwest coast. Pike and MacAskie (1969) indicated that fin whales were the most abundant of the baleen whales found along the coast of British Columbia; they were the second most important species in the commercial catch there and off the Washington coast (Scheffer and Slipp 1948). Several reports exist of fin whales sighted or captured in Puget Sound and the Strait of Georgia. Although many of the adult whales appear to be migrants traveling between summer feeding grounds in the North Pacific and winter breeding grounds to the south, young animals may reside off the Washington and British Columbia coast during the summer (Pike and MacAskie 1968).

While the little that is known of fin whale feeding in our region is to be found principally in Pike (1950), reports of their food organisms in the North Pacific include the expansive work by Nemuto (1959), and Andrews

(1909), Bethesheva (1954, 1955), Mizue (1951), Nemoto and Kasuya (1965), and Thompson (1940). Nemoto (1959) and Tomilin (1954) showed that fin whales have the second greatest number of baleen plates and the third smallest baleen fringe diameters of all the baleen whales in the North Pacific. Fin whales also have comparatively coarse baleen fringes, similar to those in blue whales. They found that euphausiids and calanoid copepods served as the primary food items and pelagic schooling fishes (primarily capelin, juvenile walleye pollock, *Theragra chalcogramma*, and Pacific herring) provided secondary contributions. *Thysanoessa inermis* and *T. longipes* were the principal euphausiid species, and *Calanus cristatus* and *C. plumchrus* the principal copepod species occurring in the samples examined by Nemoto (1959). Copepods predominated in the stomachs of whales taken offshore whereas euphausiids predominated in specimens captured along the coast (Nemoto and Kasuya 1965). Euphausiids (*T. inermis*) were the dominant prey in 48 of the 50 stomachs with food examined from Akutan, Alaska, in 1937 and 1938; walleye pollock (*Theragra chalcogramma*) and calanoid copepods (*Calanus cristatus*) predominated in the other two stomachs (Thompson 1940). Fin whales were also feeding on euphausiids (*Euphausia pacifica*, *Thysanoessa spinifera*) off the coast of California in 1937; only one of the 14 stomach samples had copepods as the prevalent prey (Thompson 1940).

Sei Whale

For many years the sei whale was largely ignored by the commercial whalers off the Pacific Northwest coast because of its small size and poor yield of oil, but it became more important with the decline of the fin whales. Of British Columbia's commercial catch from 1962 through 1966, 57% was composed of sei whales (Pike and MacAskie 1969). At the Bay City whaling station, however, only 21 sei whales were taken between 1911 and 1925 (Scheffer and Slipp 1948). There are no confirmed reports of sei whales appearing in the inland waters of Puget Sound.

Amongst the baleen whales of the North Pacific, sei whales have an intermediate number of baleen plates but have one of the lowest diameters of baleen fringes, second only to young right whales (Tomilin 1954; Nemoto 1959). The fine filtering capability of the sei's baleen morphology is reflected in the predominance of small prey organisms, almost exclusively calanoid copepods. Nemoto (1959), Nemoto and Kasuya (1965), and Kawamura (1973) illustrated that calanoid copepods, including *Calanus cristatus*, *C. plumchrus*, *C. pacificus*, and *Encalanus bungi bungi*, were the primary food species, *C. cristatus* being more dominant in offshore waters than the others. Other prey organisms occurring less frequently in the stomach contents of sei whales were euphausiids (predominantly *Euphausia pacifica*), saury, chub mackerel, Japanese sardine, *Sardinops melanostica*, and squid, *Ommastrephes sloani pacificus* (Nemoto 1959; Kawamura 1973). Fish appeared prominently in the diets of whales collected south of 40°N.

The stomach of one sei whale examined at Port Hubron, Alaska, in 1937 contained copepods, *Calanus cristatus*, and a few amphipods, whereas 12 taken in coastal California had eaten only euphausiids (Thompson 1940).

Minke (Little Piked) Whale

Because minke whales, the smallest of the baleen whales occurring along the Pacific Northwest coast, were not favored by the commercial whalers, the historical records did not reflect their actual abundance. Wahl (1977) included one report of a minke 179 km offshore Westport in September 1976. Collins (1892) and Waterman (1920) reported that the native whalers off Cape Flattery and the Strait of Juan de Fuca did take minkes. Scammon (1874) reported the first specimen taken in Puget Sound, a 27-foot female washed ashore in Admiralty Inlet. Scheffer and Slipp (1948) included four other verified reports of minke whales in various locations off Puget Sound, including Whidbey Island, McAllister Creek (Nisqually Reach), Snohomish River, and Deception Pass, and one at Waadah Island off Neah Bay. Pike and MacAskie (1969) described five records of minke whales along the British Columbia coast, but none from inside waters. Only two records of minke whales occurred in the commercial whale statistics from British Columbia (Pike and MacAskie 1969), none from Washington (Scheffer and Slipp 1948), and the one stomach of these which was examined was empty. Balcomb's (1978) 1977 Orca Survey also included 21 sightings of minke whales, all occurring in northern Puget Sound and Admiralty Inlet. One was sighted in southern Possession Sound west of Everett. Recent assessment of the survey's sighting data suggests that between 5 and 20 minke whales occur annually in the region's inland waters (Rich Osborne, Moclips Cetological Society, Orca Survey, pers. comm.).

Having an average of 280 baleen plates (per side, range 260-300), minke whales are in the group of right and gray whales, but they have baleen fringe diameters closer to sei whales and are classified as a swallowing (gulping) type (Nemoto 1959). Accordingly, their diet elsewhere in the North Pacific is quite catholic for a baleen whale, including euphausiids (*Euphausia pacifica*, *Thysanoessa inermis*, *T. longipes*, and *T. raschi*); fish (Pacific sand lance, walleye pollock, and saury);copepods (*Calanus finmarchicus*); and squid (Nemoto 1959; Omura and Sakiura 1956).

Blue Whale

Prior to the protective regulations imposed by the International Whaling Commission (IWC) in 1965, blue whales were one of the most prized catches of the commercial whalers operating off the Pacific Northwest coast. Because of their large size, speed, and tendency to pass well offshore, they were not overly abundant in the catches; only 13 were taken during the operation of the Bay City whaling station (Scheffer and Slipp 1948) and 320 in British Columbia waters (Pike and MacAskie 1969). There were no reports of blue whales naturally occurring within the region's inland waters.

Blue whale baleen is one of the coarsest filtering apparatuses amongst the baleen whales, having the highest number of baleen plates, the largest diameter baleen fringes, and the second lowest number of baleen fringes (Nemoto 1959). In the North Pacific their prey is almost exclusively the larger euphausiids (*Euphausia pacifica*, *Thysanoessa inermis*, and *T. longipes*), and only incidentally copepods (Mizue 1951; Nemoto 1959). Thompson's (1940) analysis of blue whale stomachs brought to Akutan and Port Hobron, Alaska, whaling stations substantiated their dependence upon euphausiids (primarily

T. inermis) in that region and those reported from California in that source were identical.

Humpback Whale

Humpbacks once made up the majority of whales taken commercially off the coast of Washington and British Columbia, but under heavy exploitation there and in California and Alaska they declined rapidly until the early 1960s when most of the whaling operations were forced to terminate (Scheffer and Slipp 1948; Pike and MacAskie 1969). Humpbacks were placed under IWC protection in 1966 and 1967. They appeared to represent migrants which veered inshore during their migration to Alaska in July and August. The wandering humpbacks often ventured into the inland waters of Puget Sound and the Strait of Georgia and the Strait of Juan de Fuca; Scheffer and Slipp (1948) described three such occurrences in south and central Puget Sound. Recent compilation of the Orca Survey's (Moclips Cetological Society) sighting data illustrates that about two whales venture into Puget Sound annually (Rich Osborne, pers. comm.).

Unfortunately, despite the frequency of occurrence of humpback whales, few stomachs were examined in the region. Classified as a "swallowing (gulping) type" like blue whales by Nemoto (1959), humpbacks have an intermediate number of baleen plates, mid-range baleen fringe diameters, and a number of baleen fringes similar to the blue, fin, and minke whales. Pike (1950) described the prevalence of euphausiids (Thysanoessa spinifera, Euphausia pacifica) in humpback stomachs in British Columbia, and Hewell and Huey (1930) listed the euphausiid Euphausia pacifica and Pacific sardines. In the North Pacific, euphausiids (primarily Thysanoessa inermis) were the dominant prey organisms, but schooling pelagic and epipelagic fishes (especially Atka mackerel, Pleurogrammus monopterygius, capelin, Pacific sand lance, and walleye pollock, Theragra chalcogramma) were also prominent. Thompson (1940) described the stomach contents of humpbacks taken in the western Gulf of Alaska as principally euphausiids, Thysanoessa inermis and T. gregaria, and surf smelt, Hypomesus pretiosus.

North Pacific Right Whale

Records of right whales along the coast of Washington originated primarily from unverified reports of native catches (Waterman 1920), but four were taken during the commercial whaling off British Columbia (Pike and MacAskie 1969). Scammon (1874) suggested that they were once found off Oregon, often in high numbers. Fiscus and Niggol (1965) recorded three right whales off northwest Washington in April 1959. Gilmore (1956) suggested that the coastal waters of California, Oregon, Washington, and British Columbia were wintering grounds for right whales during former periods of abundance. Although no records exist of right whales occurring in the region's inland waters, a recent sighting placed three whales off Cape Flattery (Rice and Fiscus 1968).

Neither food habits nor feeding behavior have been documented for this region. Right whales have a low number of baleen plates and the lowest diameter and highest number of baleen fringes of all the baleen whales, and are considered a unique skimming type of feeder (Nemoto 1959). As a result, the smaller planktonic crustaceans such as the copepods Calanus plumchrus and C. finmarchicus form the bulk of their diet while larger euphausiids were incidental.

D-2. Pinnipeds

Marine mammals from two pinniped families are represented in Puget Sound--Otariidae, the eared seals, and Phocidae, the earless seals. Northern fur seal, northern or Steller's sea lion, and California sea lion are Otariidae; Pacific harbor seal, Phoca vitulina richardsi, and northern elephant seal are Phocidae. Only northern sea lions and Pacific harbor seals are now prevalent in the Strait of Juan de Fuca and northern Puget Sound. The following species accounts document the trophic relationships of all pinnipeds reported from the region; however, the preceding food web discussion considers only the two prevalent species.

Species Accounts

Northern Fur Seal

Transient fur seals, migrating between their summer breeding grounds in the Bering Sea and their winter feeding grounds off California, occur along the Washington and British Columbia coasts in March, April, and May. Wahl (1977) reported sightings on 14 of 47 trips offshore Westport, Washington, mostly in May. Inshore winter residents include mostly 1- to 3-year-old seals, the older females moving farther south (Spalding 1964). Commercial sealers took large numbers offshore until the North Pacific Fur Seal Treaty of 1911, and native Indians were reported to have captured nearly 50,000 fur seals off British Columbia between 1912 and 1940 (Pike and MacAskie 1969). Apparently, many fur seals venture into the region's inland waters; Manzer and Cowan (1956) listed sightings in British Columbia's coastal waters through 1955.

Stomach contents analyses on northern fur seals in the Pacific Northwest region were performed as early as the 1930s when Clemens and Wilby (1933) and Clemens, et al. (1936), examined 593 fur seal stomachs from off the coast of British Columbia. They found that 84% of the volume of stomach contents was Pacific herring.

Kenyon's (1950a) synopsis of early food habits data on fur seals taken in coastal waters between Washington and southeastern Alaska in spring and early summer prior to 1950 indicated that Pacific herring composed almost three-quarters of the total prey composition by weight; other fish, including eulachon, Pacific salmon, Pacific sardine (pilchard) and Pacific sand lance were prey of secondary importance.

Detailed collections and examinations initiated as a result of the 1957 Interim Convention on Conservation of the North Pacific Fur Seals included 2,113 fur seal stomachs procured from 1958 to 1961 in British Columbia's coastal waters (Spalding 1964). Clupeid fishes (Pacific herring, Pacific sardine, and northern anchovy) and squid (Loligo opalescens, Gonatus magister) formed the basis of the fur seal diet. Whereas the adult seals migrating offshore the British Columbia coast fed principally upon clupeids, the diet of young seals residing in protected coastal waters from January through mid-April shifted from squid, ratfish, Hydrolagus colliei, and sablefish to only the squid Gonatus magister.

The few young animals left in the region in summer had consumed Pacific herring, Pacific hake, Pacific cod, *Gadus macrocephalus*, and various squid species; it was at this time that species of Pacific salmon entered the diet to any significance, 10% of the total food intake. Age specific food data also indicated that larger prey (Pacific salmon, Pacific cod, Pacific hake, rockfish, and shad, *Alosa* sp.) became increasingly important with increasing age of the predator.

The stomachs of fur seals taken off the coast of Washington contained, in order of decreasing volume, walleye pollock, eulachon (*Thaleichthys pacificus*), American shad (*Alosa sapidissima*), rockfish, Pacific herring, and northern anchovy (Schultz and Rufn 1936; Wilke and Kenyon 1954). Northern anchovy, rockfish, capelin, and several species of Pacific salmon (*Oncorhynchus kisutch*, *O. tshawytscha*) combined to form 92.3% of the total food volume in 190 fur seals collected off the coast of Washington in 1969 (Fiscus and Kajimura 1971). Seals taken at the entrance to the Strait of Juan de Fuca, however, appeared to have fed principally upon Pacific herring.

Wilke and Kenyon's (1952) collections of 148 fur seals from southeastern Alaska in 1950 and 1951 showed that wintering female fur seals preferred Pacific herring (99.5%) over walleye pollock (0.5%) and squid (*Loligo* sp., trace) in that region.

Capelin, eulachon, and Pacific sand lance appear to assume greater importance as the migrating fur seals move into the western Gulf of Alaska and eastern Aleutian Islands (Taylor, et al., 1955; Wilke and Kenyon 1957), and are supplemented by walleye pollock once the seals enter their summer residency in the Bering Sea (Lucas 1899; Taylor, et al., 1955; Wilke and Kenyon 1954). Pacific sand fish (*Trichodon trichodon*) composed 94.2% of the total prey volume and 99% of the total prey numbers from stomach contents of 27 fur seals collected at St. Paul Island in the Pribilof Islands, and sturgeon poacher, *Agonus acepenserinus*, composed most of the rest (Kenyon 1956).

Stomachs of 445 fur seals captured in the pelagic waters off northern Japan were reported to contain predominantly lanternfishes, 55.3% by volume, and squid (*Ommastrephes sloani pacificus*, *Watasenia scintillans*), 43.5% (Wilke 1951). Stomachs of 559 fur seals collected in November in the Sea of Okhotsk contained Asian greenling (*Pleurogrammus azonus*), Pacific sand lance, smelts (Osmeridae), walleye pollock, and Pacific salmon (Far Seas Fisheries Research Laboratory 1979). Data collected by USSR (VINRO/TINRO 1977) indicated that squid (*Gonatus magister*, *Onychoteuthis banksi*), and salmon were important prey organisms of fur seals feeding off the southeast coast of Hokkaido in 1975, and squid (*Onychoteuthis banksi*) and lanternfish of fur seals feeding near the eastern shore of Honshu in 1976.

In general, fur seals feed upon epipelagic and neritic schooling fishes and squid, usually consuming them whole underwater. Larger prey such as lingcod (*Ophiodon elongatus*), Pacific salmon, and rockfish are often brought to the surface where they are vigorously shaken apart (Spalding 1964). In almost every region, feeding appears to occur principally at night when many prey species have migrated closer to the surface (Wilke 1951; Fiscus and

Kajimura 1971; Wilke and Kenyon 1954; Fiscus, et al., 1963; Spalding 1964). Estimates of daily food consumption varied from 5% to 7% of the total body weight with an observed maximum of 10% (Spalding 1964).

Because of the composition and abundance of neritic schooling fishes in the Strait of Juan de Fuca, it is probable that fur seals feeding in that region would be utilizing Pacific herring, Pacific sand lance, surf smelt, longfin smelt (Spirinchus thaleichthys), immature Pacific salmon, and northern anchovy. Some demersal fishes such as Pacific tomcod (Microgadus proximus) and Pacific cod would probably also enter the diet incidentally.

Northern or Steller's Sea Lion

Northern sea lions reside and breed along the exposed coast of the Pacific Northwest, principally on the Scott Islands and Cape St. James in British Columbia. A 1961 census in British Columbia indicated approximately 1,500 pups and 4,500 adults residing in the province's waters (Spalding 1964). Bigg's (1973) report of California sea lion abundances on southern Vancouver Island included data on northern sea lions occupying the same haulout areas; more than 953 individuals were observed at peak abundance, occurring in December.

Wahl (1977) reported them far offshore the coast of Washington and they are commonly dispersed into the inland waters of Puget Sound and the straits of Georgia and Juan de Fuca when not occupying the rookeries in fall and winter. Preliminary results from NOAA-MESA-sponsored aerial surveys in northern Puget Sound, conducted between November 1977 and June 1978, indicated a maximum abundance at Race Rocks (southern tip of Vancouver Island) of approximately 260 individuals. Abundances declined rapidly after April when the majority of the animals departed Puget Sound (Bob Everitt, NOAA, unpubl. data).

The stomach contents of northern sea lions collected off the British Columbia coast by the Fisheries Research Board of Canada included a diverse spectrum of large prey, principally octopus, rockfish, walleye pollock, Pacific cod, Pacific hake, and spiny dogfish (Squalus acanthias) (Spalding 1964). Rockfish were the most common prey throughout the year, whereas Pacific herring was a staple prey in winter, walleye pollock in summer, and rockfish, Pacific salmon, walleye pollock, and Pacific hake in fall.

Northern sea lions widely collected along the Gulf of Alaska had fed principally upon walleye pollock (55% by volume), salmon (13.3%), starry flounder (Platichthys stellatus), octopus, skate, and Pacific tomcod; Pacific salmon, however, occurred in only two of the 15 stomachs examined (Imler and Sarber 1947). Mathisen, et al. (1962), described the principal dietary components of northern sea lions from the Shumagin Islands in the northwestern Gulf of Alaska as including nearshore fishes (mainly greenlings, Hexagrammidae, and rockfish) and invertebrates (bivalves, squid, and octopus), occurring in 42% and 85% of the stomachs, respectively. Bulls tended to consume fish more often than did cows and yearlings. There were no obvious changes in diet during or after the pupping season. Stomach contents of two sea lions from St. Paul Island in the Pribilofs were described in Wilke and Kenyon (1952) as being dominated by either Pacific sand lance or Pacific halibut with additional contributions by Pacific cod, walleye pollock, and starry flounder.

In general, northern sea lions feed predominantly upon large fish occurring throughout the water column as well as small schooling fishes when abundant in pelagic waters. Like the fur seal, sea lions prefer to bring large fish to the surface where the prey is torn apart into edible pieces by violent shaking (Spalding 1964). They also appear to be nocturnal feeders, exhibiting a decline in mean stomach contents volume from a maximum at dawn to empty 13.5 hours after sunrise. Daily food consumption has been estimated to range from 2% to 4% of the total body weight (Scheffer 1958).

California Sea Lion

Although at the northern extremity of their reported range, California sea lions have been sighted and collected along the west coast of Vancouver Island, British Columbia (Cowan and Guiguet 1965; Guiget 1953), and thus periodically may enter the Strait of Juan de Fuca to feed. Bigg's (1973) censuses along southern Vancouver Island in 1971 and 1972 provided indications of a population numbering at least 473 individuals occupying eight haulout areas. Peak abundances were recorded in February. Bigg (1973) also reported a haulout area in the Strait of Georgia on the southeastern side of Dodd Narrows.

The NOAA-MESA surveys indicated a maximum of approximately 76 California sea lions occupying the Race Rocks haulout area between December 1977 and late April 1978. Like the northern sea lion, their numbers decline rapidly thereafter as they depart Puget Sound for their breeding areas off California and Mexico (Bob Everitt, NOAA, unpubl. data).

Investigations of the food habits of California sea lions in southern California have established squid (*Loligo* sp.) and small fish (northern anchovy and Pacific hake) as their main prey items in that region (Bonnot 1928; Scheffer and Neff 1948; Fiscus and Baines 1966; Peterson and Bartholomew 1967). Mate (1973), however, found no squid in the stomachs of California sea lions collected on the Oregon coast in fall and winter.

Mate (1973) also documented a generally nocturnal feeding behavior for the Oregon sea lion population that he closely observed, showing 88% of the stomachs containing food in morning, 21% at midday, and 7% by evening. "Feeding trips" were estimated to average 4.2 days.

Although there are no data existing for the diet of California sea lions occurring in Washington and British Columbia waters, it could be assumed that their diet would be based principally upon the schooling epipelagic fishes (Pacific herring, northern anchovy, Pacific sand lance) and some of the more midwater and demersal forms (Pacific hake, Pacific cod, and walleye pollock) of the region.

Pacific Harbor Seal

The most abundant and ubiquitous pinniped occurring in the protected waters of Washington and British Columbia, Pacific harbor seals are most common in estuaries and river deltas but are seen in shallow sublittoral waters along the entire coastline and even ascend large rivers to reside in lakes (Cowan and Guiguet 1965; Pike and MacAskie 1969). Hart (1977) reported one sighting 80 km offshore Westport, Washington.

No quantitative estimates of harbor seal populations have been made for the region as a whole, although Pike and MacAskie (1969) estimated approximately one seal per mile of shoreline--e.g., 17,000 seals--for coastal British Columbia.

Aerial survey counts recently conducted by NOAA under the auspices of the MESA program have provided the first detailed inventory of harbor seals in northern Puget Sound and along the Strait of Juan de Fuca. The total number of seals enumerated during these surveys varied between 643, taken in December 1977, to 1,618 (excluding 143 pups), taken in August 1978 (Bob Everitt, NOAA, unpubl. data). Of the 17 sampling areas subdividing the region, the following eight had the highest abundances, in decreasing order: San Juan Island, Smith and Minor islands, Patos Island to Lummi Island, Rosario and Haro straits, Bellingham to Padilla Bay (all in north Puget Sound); Protection Island, Dungeness to Sequim Bay, Becher Bay to Discovery Island (along the Strait of Juan de Fuca).

Scheffer and Sperry (1931) were the first to quantitatively analyze harbor seal stomach contents from Puget Sound. The 100 stomachs examined contained, by volume, 93.6% fish (Pacific tomcod, flounder (Pleuronectidae), Pacific herring, Pacific hake, sculpin (Cottidae), codfishes (Gadidae), walleye pollock, and shiner perch, Cymatogaster aggregata), 5.8% molluscs (squid and octopus), and 0.6% crustaceans (shrimp). Scheffer (1928) had recorded the stomach contents of 22 adult harbor seals from southern Puget Sound (Nisqually Flats) to be Pacific herring, Pacific tomcod, shiner perch, sculpin, shrimp, crab, squid, octopus, skate, starfish, and flounder; only two stomachs contained remains of Pacific salmon.

The most recent and comprehensive data on harbor seal food habits in Puget Sound have been assembled by Dr. John Calambokidis (undergraduate study project, Evergreen State College, 1978), based upon the composition and abundance of fish otoliths (ear bones) in the feces deposited at haulout areas. Pacific hake (73% of total numbers), plainfin midshipman (Porichthys notatus, 7%), and staghorn sculpin (Leptocottus armatus, 6%) predominated in the overall diet combined for all regions, but there were distinct differences in the dominant prey species for the different regions of Puget Sound. Pacific hake and plainfin midshipman were most prevalent in the Hood Canal region; staghorn sculpin and Pacific hake predominated in south Puget Sound; and blackbelly eelpout (Lycodopsis pacifica), an unidentified eelpout (Lycodes sp.) and Pacific herring were most important in the region of concern, north Puget Sound (based on collections at Smith Island). Calambokidis' data also indicate some seasonal changes in the diet composition. Pacific hake clearly dominated harbor seal fish consumption in April and July through September 1977, plainfish midshipman predominated in early May, blackfin sculpin (Malacocottus kincaidi) in early June, and walleye pollock in late June.

In British Columbia, Fisher (1952) summarized the stomach contents of 50 harbor seals taken from the Fraser River, the Queen Charlotte Islands, and the Skeena River between August 1945 and November 1946. Rockfish and octopus were the most commonly occurring prey, but pink salmon (Oncorhynchus gorbuscha), Pacific herring, and other unidentified fishes composed most of the total stomach contents volume. Fisher (1952) also indicated that there was considerable temporal and spatial variability in the seals' diets and that they appear to move along the Pacific coast in response to fluctuations in abundance of preferred food organisms. Spalding's (1964) comprehensive comparison of harbor seal feeding habits with those of fur seals and sea lions along the coast of British Columbia showed a diet quite similar to the sea lions, based upon salmon, octopus, squid, clupeids, and rockfish. The contribution by Pacific salmon, however, was biased by a high number of collections made in the vicinity of salmon spawning streams in fall. Although seasonal sampling of harbor seals was inconsistent, it appeared that eulachon may be most important in winter; octopus, Pacific herring, rockfish, and salmon in summer; and salmon in fall.

Harbor seals in Alaskan waters have shown a similar feeding preference for fish, including walleye pollock and Pacific herring in Prince William Sound and eulachon at Copper River delta (Imler and Sarber 1947; Pitcher 1977), and hexagrammids (Hexagrammos lagocephalus, Pleurogrammus monopterygius) and walleye pollock in the Aleutian Islands (Wilke 1957; Kenyon 1965). Walleye pollock (83% by volume) and Pacific herring (10%) were the predominant food organisms of harbor seals sampled in the Sea of Okhotsk off Hokkaido (Wilke 1954). Octopus and squid commonly appeared in the diet in all areas, though never as a high percentage of the prey volume.

Harbor seal pups and juveniles have been reported to feed specifically upon shrimp (Havinga 1933; Fisher 1952; Bigg 1973) and small fishes (Pitcher 1977) at a general increase in prey size with increasing predator size (Spalding 1964). Unlike fur seals and sea lions, harbor seals do not appear to be nocturnal feeders (Spalding 1964). Daily food consumption by harbor seals has been estimated at 3.7% (Pitcher 1977), 5% (Havinga 1933), and 6% (Scheffer 1958) of the total body weight.

Northern Elephant Seal

Although the nearest breeding site of the northern elephant seal is 1,000 miles to the south, off southern California and Mexico, they have been reported into the Gulf of Alaska, including a specimen found at Prince of Wales Island in southeastern Alaska (Willet 1943) and several reports at Middleton Island and Baranof Island (Fiscus et al. 1977). Wahl (1977) reported three sightings between 50 and 65 km offshore Westport, Washington, and numerous sightings and specimens were reported from British Columbia, especially in Hecate Strait (Pike and MacAskie 1969). The stomach of one specimen recovered from the west coast of Vancouver Island contained hagfish. The only feeding behavior information from the Puget Sound region is of an adult male feeding upon a spiny dogfish off Point No Point in north-central Puget Sound (D. Beyer, FRI, pers. comm.).

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APPENDIX E

SEASONAL DISTRIBUTION AND ABUNDANCE OF FOOD WEB NODES AND NUMBER AND RELATIVE IMPORTANCE OF FOOD WEB LINKAGES CHARACTERIZING NEARSHORE HABITATS OF NORTH PUGET SOUND AND THE STRAIT OF JUAN DE FUCA

Appendix Table E-1. Distribution and abundance of food web nodes characterizing neritic habitats of north Puget Sound and the Strait of Juan de Fuca.

			Herbivores				Mixed		Planktivores			Benthivores			Piscivores				
Region (location)	Season	Detritus processor	Vascular plants	Suspension feeders	Microalgae grazers	Macroalgae grazers	algae detritus	Omnivores	Raptoral carnivores	Entrapment carnivores	Filter feeders	Deposit feeders	Suspension feeders	Carnivores	Pelagic	Demersal	Terrestrial origin	Non-feeding	Total nodes
Cherry Point	Spring	3		5			1		10		1				1				21
	Summer	3		2			1		8	1					1		1	6	22
	Autumn	1		1			1		3		1				1			3	11
	Winter	1		2			1	1	5		1				3			1	14
Anacortes	Spring	3		3			1		11		1				1				20
	Summer	4		3		1	1		11	1					1		1	5	28
	Autumn			1			1		2						1			3	8
	Winter	1		1			1		2		1				2			1	9
W. Whidbey I.	Spring	1		3			1		5		1				1				12
Burrows Bay	Summer	1		2					7						3			5	18
	Autumn	1		1					2		1				2			3	10
	Winter	1		2					4		2				2				10
San Juan Is.	Spring	3		3		1	1	1	8		1				1				19
	Summer	2		1		1	1	1	7	1					3			6	23
	Autumn	1		1					5	1	1				2			3	14
	Winter	1		2			1		3		2				3			1	13
Port Angeles	Spring	1		3			1		6		1				1				13
	Summer	1		2			1	1	6						4		1	6	22
	Autumn	1		1			1		3		1				2			3	12
	Winter	1		1			1		3		1				3			1	11

Appendix Table E-2. Number and relative importance of food web linkages to trophic levels characterizing neritic habitats of north Puget Sound and the Strait of Juan de Fuca. (1° = primary, 2° = secondary, 3° = tertiary, Incid = incidental trophic linkages, Nn = number of food web nodes indicated on Table E-1.)

Region (location)	Season	Detritus grazers				Phytoplankton & microalgae grazers				Macroalgae & vascular plant grazers				Mixed food consumers				Primary carnivores				Secondary carnivores				Tertiary carnivores				Subtotal				Total # linkages N_1	$\bar{x}$ No. linkages per node (N_1/Nn)
		1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid		
Cherry Point	Spring	3				5										2				2		2	3	7	8			2		10	3	13	8	34	1.62
	Summer	3				2		1								2		1		2		3	2	5	4				8	9	2	10	12	33	1.50
	Autumn	1				1										2						4			2			1	3	6		3	5	14	1.27
	Winter	1				2										5						4	2		2	1	1	1	5	8	3	6	7	24	1.71
Anacortes	Spring	3				3										2				2		3	3	6	9			2		9	3	10	9	31	1.55
	Summer	4				3				1						2		1		2		2	5	5	7				8	11	5	9	17	42	1.50
	Autumn					1										2						1		1	2				3	2		3	5	10	1.25
	Winter	1				1										2						2		3	2	1		2	1	5		7	3	15	1.67
W. Whidbey I. Burrows Bay	Spring	1				3										2				2		3	1	4	1			2		7	1	8	1	17	1.42
	Summer	1				2														2		4		3	3	1		2	8	8		7	11	26	1.44
	Autumn	1				1																2		2	1			3	3	4		5	4	13	1.30
	Winter	1				2																4		2	1	1	1			8	1	2	1	12	1.20
San Juan I.	Spring	3				3				1						2				4		4		8	6			2	1	11		16	2	29	1.53
	Summer	2				1				1						4		1		2		4		2	6	1		2	10	10		10	16	36	1.57
	Autumn	1				1												1		2		5			1			3	5	8		5	6	19	1.36
	Winter	1				3										2						2	1	3	2	1		3	3	7	1	8	5	21	1.62
Port Angeles	Spring	1				3										2				2		4	1	4	1			2		8	1	10	1	20	1.54
	Summer	1				2										4						3		4	5	1	1	2	12	7	1	10	17	34	1.55
	Autumn	1				1										2						1	3	1	3			3	3	3	3	6	6	18	1.50
	Winter	1				1										2						2	2	1	2		2	1	2	4	4	4	4	16	1.45

Appendix Table E-3. Distribution and abundance of food web nodes characterizing rocky sublittoral habitats of north Puget Sound and the Strait of Juan de Fuca.

			Herbivores				Mixed		Planktivores			Benthivores			Piscivores				
Region (location)	Season	Detritus processors	Vascular plants	Suspension feeders	Microalgae grazers	Macroalgae grazers	algae detritus	Omnivores	Raptoral carnivores	Entrapment carnivores	Filter feeders	Deposit feeders	Suspension feeders	Carnivores	Pelagic	Demersal	Terrestrial origin	Non-feeding	Total nodes
Cherry Pt. (Barnes I.)	Spring	6		2	1	1	1	3	6		1		1	9		3			34
	Summer	6		2	1	1	1	3	5		1		1	9	1	3			34
	Autumn	6		2	1	1		3	2		1		1	8	1	4			30
	Winter	6		2	1	1	1	3	1		1		1	9		4			30
W. Whidbey I. Burrows Bay (Allan I.)	Spring	6		2	1	1		3	8	1	1		1	7		3			34
	Summer	6		2	1	1	1	3	8	1	1		1	9	1	3			38
	Autumn	6		2	1	1		2	5	1	1		1	7	1	3			31
	Winter	5		2	1	1		2	3	1	1		1	7	1	2			27
San Juan Is. (Pt. George)	Spring	6		2	1	1		3	7	1	1		1	8	1	2			34
	Summer	6		2	1	1		2	6	1	1		1	9	1	5			36
	Autumn	6		2	1	1	1	3	3	1	1		1	9	1	4			34
	Winter	6		2	1	1	1	3	2		1		1	10		3			31
Strait of Juan de Fuca		4		2	1	2	1	4	6	1	1		1	9	1	5			38
Composite		6		2	1	1	2	3	14	1			1	11	5	1			48

Appendix Table E-4. Number and relative importance of food web linkages to trophic levels characterizing rocky sublittoral habitats of north Puget Sound and the Strait of Juan de Fuca. (1° = primary, 2° = secondary, 3° = tertiary, Incid = incidental trophic linkages, Nn = number of food web nodes indicated on Table E-3.)

Region (location)	Season	Detritus grazers				Phytoplankton & microalgae grazers				Macroalgae & vascular plant grazers				Mixed food consumers				Primary carnivores				Secondary carnivores				Tertiary carnivores				Subtotal				Total # linkages N_j	$\bar{x}$ No. linkages per node (N_j/Nn)
		1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid		
Cherry Point (Barnes I.)	Spring	5				4								1	2	9	2	3		3	6	2	2	9	20		2	3	3	15	6	24	31	76	2.24
	Summer	5				4								1	2	8	2	3		3	6	2	2	9	18	1	2	3	2	16	6	23	28	73	2.15
	Autumn	5				4								1	1	8	2	2	1	1	6	1	1	8	19	1	2	2	2	14	5	19	29	67	2.23
	Winter	5				4								1	2	9	2	2		1	6	1	2	9	19		2	3	3	13	6	22	30	71	2.37
W. Whidbey I. Burrows Bay (Allan I.)	Spring	5				4								1	1	8	2	2		6	6	2	1	9	20		3		3	14	5	23	31	73	2.15
	Summer	5				4								1	2	9	2	4		6	6	2	1	12	18	1	2	2	3	17	5	29	29	80	2.11
	Autumn	5				4								1	1	6	2	3		3	6		4	8	16	1	2	1	3	14	7	18	27	66	2.13
	Winter	4				4								1	1	6	2	3		3	6	1		8	16		3		1	13	4	17	25	59	2.19
San Juan Is. (Pt. George)	Spring	5				4								1	1	8	2	2	1	5	6	1	2	9	20		2	2	1	13	6	24	29	72	2.12
	Summer	5				4								1	1	6	2	4		5	6	3	1	10	20	1	2	2	3	13	4	23	31	76	2.11
	Autumn	5				4								1	2	9	2	3		3	6	2	2	9	17	1	2	2	3	16	6	23	28	73	2.15
	Winter	5				4								1	2	9	2	2		1	6	3	1	7	17		1	4	2	15	4	21	27	67	2.16
Strait of Juan de Fuca		3				4				1				1	2	10	4	3		3	6	1	3	15	20	1	1	4	6	13	6	32	36	87	2.29

Appendix Table E-5. Distribution and abundance of food web nodes characterizing rocky and cobble littoral habitats of north Puget Sound and the Strait of Juan de Fuca.

			Herbivores				Mixed		Planktivores			Benthivores			Piscivores				
Region (location)	Season	Detritus processor	Vascular plants	Suspension feeders	Microalgae grazers	Macroalgae grazers	algae detritus	Omnivores	Raptoral carnivores	Entrapment carnivores	Filter feeders	Deposit feeders	Suspension feeders	Carnivores	Pelagic	Demersal	Terrestrial origin	Non-feeding	Total nodes
Rocky																			
Strait of Juan	Spring	6		3	2	2	2		10				1	14		1			41
de Fuca and	Summer	7		3	2	2	3		9				1	13		1			41
San Juan Is.	Autumn	6		3	2	2	2		9				1	12		1			38
	Winter	7		3	2	2	3		8				1	14		1			41
Cobble																			
Strait of Juan	Spring	4		3	2		2	1	6	1			1	10		2			32
de Fuca and	Summer	6		3	1	1	2	1	5	1			1	10		2			33
San Juan Is.	Autumn	5		3	2	1	2	1	5	1			1	11		2			34
	Winter	6		3	2	1	2	1	6	1			1	10		2			35
Composite		5		3	2	1	2	1	4	1			1	12		3			35

Appendix Table E-6. Number and relative importance of food web linkages to trophic levels characterizing rocky and cobble littoral h bitats of north Puget Sound and the Strait of Juan de Fuca. (1° = primary, 2° = secondary, 3° = terti ry, Incid = incidental trophic linkages, Nn = number of food web nodes indicated on Table E-5.)

Region (location)	Season	Detritus grazers				Phytoplankton & microalgae grazers				Macroalgae & vascular plant grazers				Mixed food consumers				Primary carnivores				Secondary carnivores				Tertiary carnivores				Subtotal				Total # linkages N_1	$\bar{x}$ No. linkages per node (N_1/Nn)
		1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid		
Rocky																																			
Strait of Juan	Spring	6				5	1			2	1		1	2	2			1	1	4	16	3	4	21	1			11	2	17	9	38	19	83	2.02
de Fuca and	Summer	7				5	1			2	1		1	2	4			2	1	4	16	2	4	19	6			10	1	18	9	37	23	87	2.12
San Juan Is.	Autumn	6				5	1			2	1		1	2	2			1	1	4	16	1	7	16	1			11	2	15	12	33	19	79	2.08
	Winter	7				5	1			2	1		1	3	3			1	1	4	16	2	4	16	7			10	2	17	10	33	25	85	2.07
Cobble																																			
Strait of Juan	Spring	3				4								2	4				1		3	2	3	9	15			11	8	9	6	24	26	65	2.03
de Fuca and	Summer	4				3				1				2	4				1		3	2	2	6	15			12	7	10	5	22	25	84	2.54
San Juan Is.	Autumn	4				4				1				2	4				1		3		1	17	13			12	9	9	4	33	25	71	2.08
	Winter	5				4				1				2	4			2				1	3	9	17			11	9	13	5	24	26	68	1.94

Appendix Table E-7. Distribution and abundance of food web nodes characterizing gravel-cobble shallow sublittoral habitats of north Puget Sound and the Strait of Juan de Fuca.

			Herbivores				Mixed		Planktivores			Benthivores			Piscivores				
Region (location)	Season	Detritus processor	Vascular plants	Suspension feeders	Microalgae grazers	Macroalgae grazers	algae detritus	Omnivores	Raptoral carnivores	Entrapment carnivores	Filter feeders	Deposit feeders	Suspension feeders	Carnivores	Pelagic	Demersal	Terrestrial origin	Non-feeding	Total nodes
Cherry Point	Spring	5					1	4	4					3		1	1		19
	Summer	4					1	2	5					2		1			15
	Autumn	5		1	1		3	4	8				1	8		2	1		34
	Winter	4		2		1	2	3	4				1	9		2			27
(Legoe Bay)	Spring	4		1			3	5	6					6		1	1		27
	Summer	5		2	1		3	5	7					6		1	1		31
	Autumn	5		2	1		2	5	12	1			1	8		2	1		40
	Winter	3			1			3	6				1	3		2	1		20
Anacortes (Guemes S.)	Spring	5		2			1	3	3				1	6		1			22
	Summer	5		1	1		2	4	4					6		1			24
	Autumn	5		2	1		3	4	10	1			1	13		2			42
	Winter	4		2			2	4	3	1			1	9		2			28
W. Whidbey I. Burrows Bay (Alexander's Beach)	Spring	4					1	2	1					5		1			14
	Summer	5					1	2	1				1	4		1			15
	Autumn	5					1	3	5				1	10		2			27
	Winter	5						3	1				1	4		2			16
(West Beach)	Spring	5		1				3	3					3		2			17
	Summer	4					1	3	4					9		1			22
	Autumn	5					2	4	3				1	10		1			26
	Winter	4					2	2	1				1	6		2	1		19
San Juan Is. (Deadman Bay)	Spring	4		1			2	4	13	1				4		1			30
	Summer	5		1			2	5	16	1			1	11		1			43
	Autumn	5		1			3	3	8	1			1	16		2			40
	Winter	4		1			2	4	12				1	7		2			33
(South Beach)	Spring	4					1	4	6				1	6		1			23
	Summer	4		1	1		3	5	12	1			1	11		1			40
	Autumn	4			1		1	5	6	1			1	9		1			29
	Winter	4		1			1	4	4	1			1	8		2			26

Appendix Table E-7, cont'd

			Herbivores						Planktivores			Benthivores			Piscivores				
Region (location)	Season	Detritus processor	Vascular plants	Suspension feeders	Microalgae grazers	Macroalgae grazers	Mixed algae detritus	Omnivores	Raptoral carnivores	Entrapment carnivores	Filter feeders	Deposit feeders	Suspension feeders	Carnivores	Pelagic	Demersal	Terrestrial origin	Non-feeding	Total modes
Port Angeles (Dungeness Spit)	Spring	5					1	2	1					6		1			16
	Summer	4					1	1	2					6		1			15
	Autumn	3					1	3	2					4		2			15
	Winter	5					1	2	1					5		2			16
(Morse Creek)	Spring	6		1	1		2	2	3					7		1			22
	Summer	6			1		2	3	3					6		1			22
	Autumn	4					2	2	1					6		2			17
	Winter	4					1	2						7		2			16
(Kydaka Beach)	Spring	4					2	2	1					4					13
	Summer	4					1	2						7		1			15
	Autumn	3					1	2	1					4		2			13
	Winter	3					2	2	1					5		2			15

Appendix Table E-8. Number and relative importance of food web linkages to trophic levels characterizing gravel-cobble shallow sublittoral habitats of north Puget Sound and the Strait of Juan de Fuca. (1° = primary, 2° = secondary, 3° = tertiary, Incid = incidental trophic linkages, Nn = number of food web nodes indicated on Table E-7.)

Region (location)	Season	Detritus grazers				Phytoplankton & microalgae grazers				Macroalgae & vascular plant grazers				Mixed food consumers				Primary carnivores				Secondary carnivores				Tertiary carnivores				Subtotal				Total # linkages N_1	$\bar{x}$ No. linkages per node (N_1/Nn)
		1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid		
Cherry Point	Spring	4	1		1	1									1	6	7				4	3	3	3	4				2	8	5	9	18	40	2.11
	Summer	4														4	3				4	5	2		3				2	9	2	4	10	25	1.67
	Autumn	4			1	2			1	2					3	7	6				4	7	5	7	7				6	13	8	14	25	60	1.76
	Winter	4	1			4			1	2					2	6	4				4	3	5	7	7				4	13	8	13	20	54	2.00
(Legoe Bay)	Spring	4	1		1	2			1						2	4	6				4	7	4	3	5				3	13	7	9	20	49	1.81
	Summer	5	1		1	3			1						2	7	6				4	6	5	7	6				1	14	8	14	19	55	1.77
	Autumn	4	1		1	4			1	2					1	9	6			2	4	5	7	13	5				7	13	9	22	25	69	1.73
	Winter	4				3			1	2						3	6	1		2	4	3	2	6	1				2	13	2	11	12	38	1.90
Anacortes (Guemes, S.)	Spring	4	1		1	3			1						1	5	4				4	2	4	5	6				2	9	6	10	18	43	1.95
	Summer	4	1		1	3									2	7	5				4	5	3	6	4				2	12	6	13	16	47	1.96
	Autumn	4	1		1	3			1						3	8	5	2		2	5	10	6	15	5				7	19	10	25	24	78	1.86
	Winter	3	1		1	2			1						2	7	5	2		2	5	4	4	9	3				4	11	7	18	19	55	1.96
W. Whidbey I. Burrows Bay (Alexander's Beach)	Spring	4														4	4	1			5		3	7					1	5	3	11	10	29	2.07
	Summer	5				1			1							4	4	1			4	1	1	5	2				1	7	1	9	12	29	1.93
	Autumn	4				1			1							4	4	1			4	6	4	7	4				5	12	4	11	18	45	1.67
	Winter	5				1			1							4	5				4	2	1	5	1				2	8	1	9	13	31	1.94
(West Beach)	Spring	5				1									1	3	4				4	2	2	5	2				3	8	3	8	13	32	1.88
	Summer	4													1	5	4	1			4	5	4	8	3				5	10	5	13	16	44	2.00
	Autumn	5				1			1						2	8	5	1			4	4	5	9	7				[illegible]	10	7	17	21	55	2.12
	Winter	4				1			1						1	5	4				4	2	1	6	3				3	7	2	11	15	35	1.84
San Juan Is. (Deadman Bay)	Spring	4				1									2	8	4	2		2	4	9	2	10	6				2	16	4	18	16	54	1.80
	Summer	5				2			1						3	8	4	2		2	4	9	7	15	15				5	18	10	23	29	80	1.86
	Autumn	5				2			1						2	8	4	2		2	4	10	5	14	11				7	19	7	24	20	70	1.75
	Winter	4				2			1						2	7	5	2		2	4	10	3	9	4				9	18	5	18	23	64	1.94

Appendix Table E-8, cont'd

Region (location)	Season	Detritus grazers				Phytoplankton & microalgae grazers				Macroalgae & vascular plant grazers				Mixed food consumers				Primary carnivores				Secondary carnivores				Tertiary carnivores				Subtotal				Total # linkages N_1	$\bar{x}$ No. linkages per node (N_1/Nn)
		1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid		
(South Beach)	Spring	4				1			1						2	6	4				4	4	4	9	7				4	9	6	15	20	50	2.17
	Summer	5				3			1						4	10	3	1		2	4	7	7	19	17				6	16	11	31	25	83	2.08
	Autumn	4				3			1						2	8	3	1		2	4	7	2	7	10				5	15	4	17	23	59	2.03
	Winter	4				2			1						2	6	4	1		2	4	4	2	6	7				5	11	4	14	21	50	1.92
Port Angeles (Dungeness Spit)	Spring	5														4	4	1	1		5	1	2	3	4				2	7	3	7	13	30	1.88
	Summer	4														2	3	1			4	4	3	2	2				2	8	3	4	11	26	1.73
	Autumn	3													1	5	4	1			4	2	2	2	2				4	6	3	7	14	30	2.00
	Winter	5														4	4	1			4	1	2	5	1				5	6	2	9	14	31	1.94
(Morse Creek)	Spring	6				2									1	5	4	1	1		5	1	4	8	10				3	10	6	13	22	51	2.32
	Summer	6				1									2	6	4	1			4	2	1	7	8				1	10	3	13	17	43	1.95
	Autumn	4													1	5	4	1			4		2	9	3				5	5	3	14	16	38	2.24
	Winter	4														4	4	1	1		5		3	6	4				5	5	4	10	18	37	2.31
(Kydaka Beach)	Spring	4													1	5	4				4	2	1	5	2					6	2	10	10	28	2.15
	Summer	4														4	4	1			4	1	4	3	6				2	6	4	7	16	43	2.87
	Autumn	3													1	3	4	1			4	1	2	2	2				3	5	5	3	13	26	2.00
	Winter	3													1	5	4	1			4	3	1	3	2				4	7	2	8	14	31	2.07

Appendix Table E-9. Distribution and abundance of food web nodes characterizing sand/eelgrass shallow sublittoral habitats of north Puget Sound and the Strait of Juan de Fuca.

Region (location)	Season	Detritus processor	Herbivores				Mixed algae detritus	Omnivores	Planktivores			Benthivores			Piscivores		Terrestrial origin	Non-feeding	Total nodes
			Vascular plants	Suspension feeders	Microalgae grazers	Macroalgae grazers			Raptoral carnivores	Entrapment carnivores	Filter feeders	Deposit feeders	Suspension feeders	Carnivores	Pelagic	Demersal			
Cherry Point (Birch Bay)	Spring	5	2		1		4	4	5					12					33
	Summer	4			1		4	4	6					13					33
	Autumn	4	2	1	1		2	4	5					13					32
	Winter	4	3	1			2	4	3					9					26
San Juan Is. (Eagle Cove)	Spring	4	2				2	2	2					10					22
	Summer	4					3	3	5					10					25
	Autumn	4	2				3	4	7					10					30
	Winter	3	3				2	2	1					8					19
Strait of Juan de Fuca (Beckett Pt.)	Spring	3	1				2	4	2					10					22
	Summer	4			1		2	3	7					10					27
	Autumn	3	2				2	4	4					7					22
	Winter	3	3	1			2	6	6					11					32
(Twin Rivers)	Spring	3	1				4	3	6					9					26
	Summer	3		1			4	5	9					9					31
	Autumn	4		2			3	4	6					9					28
	Winter	3	2				3	4	5					8					25

Appendix Table E-10. Number and relative importance of food web linkages to trophic levels characterizing sand/eelgrass shallow sublittoral habitats of north Puget and the Strait of Juan de Fuca. (1° = primary, 2° = secondary, 3° = tertiary, Incid = incidental trophic linkages, Nn = number of food web nodes indicated on Table E-9.)

Region (location)	Season	Detritus grazers				Phytoplankton & microalgae grazers				Macroalgae & vascular plant grazers				Mixed food consumers				Primary carnivores				Secondary carnivores				Tertiary carnivores				Subtotal				Total # linkages N_1	$\bar{x}$ No. linkages per node (N_1/Nn)
		1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid		
Cherry Point	Spring	5				1				2					6	10	6			2	2	4	4	16	11					12	10	28	19	69	2.09
(Birch Bay)	Summer	4				1									6	12	6	1		2	2	5	4	16	11					11	10	30	19	70	2.12
	Autumn	4				2				2					4	8	6	1		2	2	4	4	19	8					13	8	29	16	66	2.06
	Winter	4				1				3					4	7	7			2	2	1	3	15	4					9	7	24	13	53	2.04
San Juan Is.	Spring	4								2					3	6	6			2	2	1	3	15	9					7	6	23	17	53	2.41
(Eagle Cove)	Summer	4													3	9	6			2	2	3	4	13	12					7	7	24	20	58	2.32
	Autumn	4								2					3	11	6			2	2	2	7	16	11					8	10	29	19	66	2.20
	Winter	3								3					3	5	6			2	2		3	11	2					6	6	18	10	46	2.42
Strait of	Spring	3								1					2	10	6			2	2	5	1	12	9					9	3	24	17	53	2.41
Juan de Fuca	Summer	4				1									2	10	7		1	2	3	5	5	11	10					10	8	23	20	71	2.63
(Beckett Pt.)	Autumn	3								2					2	9	7			2	2	1	1	17	5					6	3	28	14	51	2.32
	Winter	3				1				3					2	14	6			2	2	3	4	17	11					10	6	33	19	68	2.13
(Twin Rivers)	Spring	3								1					4	10	6			2	2	5	4	12	10					9	8	24	18	59	2.27
	Summer	3				1									4	14	7			2	2	6	7	12	10					10	11	28	19	67	2.16
	Autumn	4				2									3	13	7			2	2	4	5	13	9					10	8	28	18	64	2.29
	Winter	3								2					3	11	7			2	2	2	6	11	5					5	9	24	14	52	2.08

Appendix Table E-11. Distribution and abundance of food web nodes characterizing mud/eelgrass shallow sublittoral habitats of north Puget Sound and the Strait of Juan de Fuca.

			Herbivores				Mixed		Planktivores			Benthivores			Piscivores				
Region (location)	Season	Detritus processor	Vascular plants	Suspension feeders	Microalgae grazers	Macroalgae grazers	algae detritus	Omnivores	Raptoral carnivores	Entrapment carnivores	Filter feeders	Deposit feeders	Suspension feeders	Carnivores	Pelagic	Demersal	Terrestrial origin	Non-feeding	Total nodes
Anacortes	Spring	4	2	1	1		1	5	8					5		4			31
(Fidalgo Bay)	Summer	4		1	1		1	6	5					8		1			27
	Autumn	4	2	2	1		1	8	3					11		1			33
	Winter	4	4	2	1	1	2	5	4					9		1			33
San Juan Is.	Spring	4		1			3	5	9					8		1			31
(Westcott Bay)	Summer	4		3			2	8	10			1		11		1			40
	Autumn	4		3		1	1	8	9			1		10		1			38
	Winter	4	1	2			1	3	6					6		1			24
Port Angeles	Spring	5	3	1	1	1	2	3	6			1		16		1			40
(Jamestown-	Summer	2		2			1	4	4					5		1			19
Graysmarsh)	Autumn	3	2	1			2	6	5					6		1			26
	Winter	3	4	1			1	4	2					6		1			22

Appendix Table E-12. Number and relative importance of food web linkages to trophic levels characterizing mud/eelgrass shallow sublittoral habitats of north Puget Sound and the Strait of Juan de Fuca. (1° = primary, 2° = secondary, 3° = tertiary, Incid = incidental trophic linkages, Nn = number of food web nodes indicated on Table E-11.)

Region (location)	Season	Detritus grazers				Phytoplankton & microalgae grazers				Macroalgae & vascular plant grazers				Mixed food consumers				Primary carnivores				Secondary carnivores				Tertiary carnivores				Subtotal				Total # linkages N_l	$\bar{x}$ No. linkages per node (N_l/Nn)
		1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid	1°	2°	3°	Incid		
Anacortes (Fidalgo Bay)	Spring	4				2				2					2	6	4		1	2	2	6	3	8	18			2	2	14	6	18	26	64	2.06
	Summer	4				2									1	17	8		1	5	2	3	3	5	6			2	2	9	5	29	18	61	2.26
	Autumn	4				3				2					2	21	4		1	2	2	1	3	9	9			2	2	10	6	34	17	67	2.03
	Winter	4				3				4					2	13	5		1	2	2	3	3	9	4			2	1	14	6	25	13	57	1.73
San Juan Is. (Westcott Bay)	Spring	4				1									4	12	5		2	2	2	2	6	8	12			2	1	7	12	24	20	63	2.03
	Summer	4				3								1	3	21	5		2	2	2	2	7	9	18			2	2	10	12	34	27	83	2.08
	Autumn	4				3				1					2	21	5		2	2	2	1	7	12	22			2	1	9	11	37	31	87	2.29
	Winter	4				2				1					1	9	4		2	2	2		5	4	8			2	1	7	8	17	15	47	1.96
Port Angeles (Jamestown-Graysmarsh)	Spring	5				2				4					2	10	6		2	2	2	5	4	6	31			2	2	16	8	20	41	85	2.13
	Summer	2				2									1	11	4			2	2	2	4	5	2			2	1	6	5	20	9	40	2.11
	Autumn	3				1				2					2	18	4		1	2	2	1	5	4	8			2	1	7	8	26	15	62	2.38
	Winter	3				1				4					1	11	4			2	2		3	7	4			2		8	4	22	10	44	2.00

APPENDIX F

MECHANISMS OF PETROLEUM HYDROCARBON INFLUENCE UPON FOOD WEB STRUCTURE

F-1. Effects Upon and Within Marine Organisms

The literature describing the biological effects of petroleum hydrocarbons on marine organisms is extensive. Recent symposia and syntheses have summarized the state of the knowledge (Baker 1978; Am. Inst. Biol. Sci. 1976; Wolfe 1977; Malins 1977; McIntyre and Whittle 1977; Fish. Res. Board Can. 1978) and the reader is referred to these for a thorough discussion of petroleum in marine ecosystems. Documentation of the acutely toxic levels and fractions of petroleum hydrocarbons has provided accurate indications of short-term effects on marine biota (Craddock 1977). In the long run, however, sublethal or chronic effects may be more important to food web structures than acute effects, in that subtle changes in behavior, growth, natural mortality, reproduction, and general physiological condition may alter or eliminate critical predator-prey linkages (Blumer 1970; Sprague 1971; Tarzwell 1971). A brief introduction to biological fate and effects in selected marine organisms is necessary for our understanding of the potential incorporation and transfer of petroleum hydrocarbons in food webs of north Puget Sound and the Strait of Juan de Fuca.

F-1-a. Toxic Components

Of the two basic categories of the water-soluble fractions of petroleum oils, the volatile and the non-volatile, the volatile components have generally been shown the more toxic, and thus have received the most attention (Moore and Dwyer 1974; Donahue, et al., 1977; Lee, et al., 1978; Struhsaker 1977; Morrow, et al., 1975). Although more persistent and more likely to enter the food web, non-volatile aromatics and their biological effects have not been as well studied (Emery 1970; Winters, et al., 1976). For example, Lee and Nicol (1978) pointed out that although the volatile aromatics were measurably more toxic to the marine amphipod *Elasmopus pectenicrus*, the concentrations which induced acute mortality were higher than would naturally occur in the water-soluble fraction. The non-volatile aromatics, although much less toxic, had a greater potential of biological interaction with the marine organism because of their persistence at high concentrations in the environment.

F-1-b. Uptake, Retention, and Depuration

Uptake and retention of petroleum hydrocarbons appear to vary according to the type as well as the form of hydrocarbon. In general, aromatic hydrocarbons of high molecular weight will be retained in an organism's tissues longer than hydrocarbons of low molecular weight, total release of hydrocarbons requiring from 2 to 60 days (Neff, et al., 1976). Concentrations of aromatics in tissues are assumed to reach an equilibrium with external concentrations, and hydrocarbons of lighter molecular weight tend to reach this equilibrium at a faster rate than heavier compounds. Retention of petroleum hydrocarbons in animal tissues appears to be a passive process, primarily through the partitioning of the hydrocarbons between the water and tissue lipids (Neely, et al., 1974; Neff, et al., 1976). Active biological processes such as ventilation, blood circulation, excretion, and hydrocarbon metabolism determine the actual uptake and release.

According to Stone (1975) and Neff, et al. (1976), the incorporation of hydrocarbons with tissue lipids is probably by hydrophobic interaction, which means that the hydrocarbons remain in an exchangeable form. Exposure to petroleum hydrocarbons for a long period of time, however, allows a small fraction to enter a stable state in the tissue from which it is not readily exchangeable (Stegeman and Teal 1973; DiSalvo, et al., 1975; Neff, et al., 1976). When the organism is eventually re-exposed to hydrocarbon-free water, hydrocarbon is released from this stable fraction more slowly than hydrocarbon is bound by hydrophobic reaction.

Experiments on the uptake and fate of petroleum hydrocarbons (radio-labelled paraffinic and aromatic hydrocarbons) by the blue crab Callinectes sapidus indicated that up to 10% of the hydrocarbons can be taken up from either water or food organisms (Lee, et al., 1976). All the assimilated hydrocarbons were metabolized or eliminated through fecal matter. More than half of the metabolic activity involving the labelled hydrocarbons occurred in the hepatopancreas, which was the only site of radioactivity 25 days after exposure. In fish, however, the liver and gall bladder appear to be the primary organs involved in the metabolism of hydrocarbons ingested or assimilated (Lee, et al., 1972).

Both feeding mode and intrinsic capabilities appear to determine the extent of hydrocarbon uptake by benthic invertebrates. Roesijadi, et al. (1978), conducted experiments with deposit-feeding bivalves (Macoma inquinata) and sipunculids (Phascolosoma agassizi) and suspension-feeding bivalves (Protothaca staminea) exposed to aliphatic and diaromatic hydrocarbons. In general the deposit feeders accumulated the hydrocarbons to a greater extent than did the suspension feeders. Roesijadi, et al. (1978), also indicated that compounds of higher molecular weight will be relatively persistent in the tissue of exposed bivalves.

Even though depuration or release of assimilated petroleum is usually rapid, it is most often incomplete. Small quantities of hydrocarbons are often retained long enough to be transferred to a higher trophic level. Lee (1975) found that detectable residues of labelled benzo(a)pyrene were evident in Calanus helgolandicus after 9 days, in C. plumchrus after 16 days, and in C. hyperboreus after 4 weeks. Molluscs appear to be unable to metabolize hydrocarbons (Lee, et al., 1972; Carlson 1972) but able to eliminate accumulated hydrocarbons by depuration (Lee, et al., 1972; Stegeman and Teal 1973; Neff and Anderson 1975).

F-1-c. Detection and Avoidance

Many references suggest that fish have the ability to avoid petroleum hydrocarbon-saturated waters (Boesch, et al., 1974; North, et al., 1965), especially offshore waters. The ability of many fish to detect petroleum hydrocarbons at low levels has been illustrated in several cases but there are a number of contradicting reports (Patten 1977). Syazuki (1964) showed that goby (Chaenogobius heptacanthus), crescent perch (Therapon jarbua), and striped mullet (Mugil cephalus) exhibited threshold responses at between 0.7 ppm for crude oil and 48 ppm for "Mobil" oil. Larvae of Atlantic cod (Gadus morhua), Atlantic herring (Clupea harengus harengus), and plaice (Pleuronectes platessa), however, showed no ability to avoid water contaminated by three different types of crude oil (Kuhnhold 1970). Rice (1973) showed that the ability of juvenile pink salmon (Oncorhynchus gorbuscha) to avoid water-soluble fractions of Prudhoe Bay crude oil in a flowthrough system varied according to the fishes' adaptation to sea water, their age, and possibly the water temperature; in sea water the avoidance level ranged from 1.6 ppm to 16.0 ppm.

F-2. Indirect Sublethal Effects

F-2-a. Effects on Reproduction, Growth, and Metabolism

Incorporation of sublethal levels of hydrocarbons into tissues has also been shown to alter reproductive success of crustacean populations by decreasing egg production, increasing mortality rates for egg and larval stages, and altering basic metabolic processes (Johnson 1977).

Donahue, et al. (1977), examined the physiological response of mud crab (Rhithropanopeus harrisi) larvae continuously exposed to naphthalene or phenanthrene under different regimes of temperature and salinity and found decreased survival to metamorphosis, increased duration of larval development, increased respiratory rates, and increased sensitivity to acute salinity stress. They concluded that sublethal hydrocarbon stress acted to divert assimilated energy from growth to maintenance processes.

Water-soluble fractions of No. 2 fuel oil were lethal to the amphipod Elasmopus pectenicrus at 4 ppm for short exposure periods, but growth and fecundity were inhibited at lower concentrations of 0.6 and 0.2 ppm, respectively (Lee, et al., 1977). When adult isopods (Sphaeroma quadridentatum) were exposed to low levels of oil for one month, the juvenile stages suffered significantly higher mortalities, more than 70% in five weeks (Lee and Nicol 1977). In oil concentrations of 0.3 to 0.4 ppm, the amphipod Gammarus oceanicus produced significantly fewer larvae than the controls in experiments conducted by Linden (1976). Ustach (1977) found that the soluble fraction from 200 μl crude oil per liter sea water significantly reduced egg production by the harpacticoid copepod Nitocra affinis, as well as one-half and one-fourth dilutions; the mean length of life and the mean number of broods were not significantly affected.

Decreasing fecundity and rate of egg laying have also been shown to result in birds which had consumed petroleum (Hartung 1963; Grau, et al., 1977); this may be a function of both direct deposition in the ovary by transport through the intestinal tract and liver and by changes in the ion composition of the yolk as a result of osmoregulatory inhibition (Crocker, et al., 1974, 1975; Grau, et al., 1977).

Oritsland (1975) found that fresh Norman Wells crude oil did not significantly change the insulating values of ringed seal fur in air and at varying wind speeds. It was suggested, however, that the solar heating of the seal's skin during haulout would be increased.

Enzymatic and histological evidence of kidney damage, possibly due to an unsuccessful attempt to concentrate or excrete the oil or its metabolites through the urinary system, was evidenced in Smith and Geraci's (1975) oil immersion studies with ringed seals, Phoca hispida. They suggested that 25 ml to 75 ml ingested crude oil would probably represent the upper limit of what an animal might ingest without irreversible damage. Thus, ingestion of oil by immersed seals may not be significant except through the consumption of live contaminated prey. However, an accumulation of over 75 ml of petroleum hydrocarbons by this route of entry would require significant levels of the toxicant in the prey.

Geraci and Smith (1977) suggested that more important consequences of an oil pollution incident may be eye damage, prolonged moulting, and the influence of oil on stress of the pinnipeds, rather than accumulation of petroleum hydrocarbons in tissues. Starvation would probably result. Pollution incidents would tend to be more detrimental to older seals and seals in poor nutritional condition.

F-2-b. Tainting of Tissue by Accumulated Petroleum Hydrocarbons

Long-term incorporation of hydrocarbons by predators also has the potential to limit their utilization as food by man. Even though most marine organisms are capable of eventually depurating or metabolizing assimilated hydrocarbons, those of commercial value which may smell and taste in a manner reminiscent of petroleum, will be unmarketable for a long time (Blumer, et al., 1970; Bourcat and Mallet 1965; Cahnmann and Kuratsune 1957; Mackie, et al., 1972; Nitta, et al., 1965; Shipton, et al., 1970; Vale, et al., 1970).

F-3. Uptake and Effects of Petroleum Hydrocarbons Transferred Via Food Web Linkages

F-3-a. Food Web Biomagnification

While there has been much discussion of the potential for biomagnification of petroleum hydrocarbons with transfer through the food web, no definitive studies have illustrated such a phenomenon. In fact, although most marine organisms are capable of accumulating high concentrations (200-300 times in crustaceans and fish) directly from sea water, there is no evidence that petroleum burdens in tissues actually increase at higher trophic levels (Varanasi and Malins 1977).

F-3-b. Transmittal via Food Web Linkages

Trophic transfer, i.e., from prey to predator, of petroleum is well documented, however, and there is good evidence of sublethal effects resulting from the incorporation or metabolism of the hydrocarbons by the consumer.

Corner, et al. (1976), found that at least for zooplankton, uptake of hydrocarbons via food particles was a more significant and longer-lasting route than via direct uptake from the water solution. Not only was the total accumulation of hydrocarbons (naphthalene) higher from the food web transfer but depuration was considerably slower such that a third of the radiolabelled hydrocarbons remained in calanoid copepods ten days after exposure to contaminated food particles. Conover (1971) found that copepods (*Temora longicornis*, *Calanus finmarchicus*) ingested suspended bunker C oil particles from the ARROW spill in Chedabucto Bay and accounted for up to 10% of the oil in the water column. Ingestion of the oil had no apparent effect on the copepods, as they passed it with their feces which were shown to contain up to 7% oil. This mechanism was considered to be one of the most important pathways of the pollutant between the pelagic and the benthic systems--as much as 20% of the total suspended particulate oil was estimated to precipitate to the bottom as zooplankton feces. Parker, et al. (1971), calculated that the calanoid copepod *Calanus finmarchicus* could graze up to 1.5×10^{-4} g of oil per day. Thus, assuming a density of 2,000 per m^3 over a 1-km^2 area to 10 m depth, as much as three tons of oil could be encapsulated and precipitated as feces per day!

Such high rates of uptake illustrate the rapidity with which suspended petroleum can be biologically converted into a form available for ingestion by higher trophic level organisms, through ingestion of either the contaminated copepods by pelagic carnivores or of their feces by benthic detritivores.

The predators of the hydrocarbon-burdened zooplankton, unlike the zooplankton, will often incorporate the hydrocarbon into their tissues rather than excrete it. Post yolk-sac larvae of Pacific herring (*Clupea harengus pallasi*) that were fed rotifers (*Brachionus plicatilis*) containing high accumulated levels of labelled benzene rapidly incorporated the monoaromatic hydrocarbon into their tissues (Struhsaker 1977). Assimilation of the hydrocarbons or metabolism products usually takes place in high-lipid tissues, especially the reproductive organs. In this case, effects upon the organism's reproductive efficiency result. Struhsaker's (1977) exposure of female Pacific herring to the aromatic hydrocarbon benzene caused a pronounced reduction in survival of the ovarian eggs and resultant embryos and larvae through yolk absorption; the later life history stages suffered the highest mortality, 43%. Again, the total effect of incorporation of the hydrocarbons into the food web would not be manifested until the next generation of the carnivore populations, which in some cases might not occur for two to three years.

Ogata, et al. (1977), documented the accumulation of paraffins, organic sulfur compounds, and aromatic hydrocarbons by eels reared in a crude oil suspension. Paraffinic hydrocarbons were detected in salmon (*Oncorhynchus keta*), mullet (*Mugil cephalus*), and black sea bream (*Mylio macrocephalus*) collected from waters polluted by a crude oil spill outside Niigata Harbor in the Sea of Japan (Motohiro and Inoue 1973). Indications of higher n-paraffin concentrations in the digestive organs suggested that the hydrocarbon contamination in this case was acquired principally through feeding. Brown trout (*Salmo trutta*) collected 11 days after a diesel fuel spill were found to still contain n-paraffin (C_{13}-C_{19}) hydrocarbon compounds

(Mackie, et al., 1972). These results showed that many of the aliphatic saturated hydrocarbons and possibly some of the aromatics characteristic of the spilled diesel oil were also present in the flesh of the trout.

F-4. Ecological Effects of Petroleum Hydrocarbons

F-4-a. Vulnerability of Lower Trophic Levels

Studies of the toxicity of petroleum hydrocarbon components to marine biota indicate that in general the lower the trophic level, the more sensitive the organism. For example, marine crustaceans are more vulnerable to petroleum hydrocarbons than are marine fish and marine mammals. This suggests that although the organisms at the upper end of the food web, which are most often utilized by man, have greater tolerance of the effects of petroleum hydrocarbons in the marine environment, the productivity and stability of lower trophic levels can be altered to the point where basic food limitations can be effected upon the higher consumers. This process is potentially one of the longest lasting and most deleterious effects of petroleum pollution, and it has to be the most difficult to detect, considering the present knowledge of food web dynamics and natural variability in food resources and the consequential effects on the consumers.

F-4-b. Disruption of Autotrophic Production

It is not unreasonable to assume that some effects are going to be manifested at the very base of the trophic pyramid, the photosynthetic generation of carbon by phytoplankton. The presence of oil, undergoing the processes of weathering and degrading on the surface film, can radically alter the utilization of organic and inorganic nutrients (nitrogen, phosphorus) by the primary producers (Williams 1967; Feldman 1973). No. 2 and No. 3 fuel oils and Venezuelan crude oil generally inhibited phytoplankton growth at concentrations greater than 30-50 μg/l in radiocarbon-uptake experiments by Gordon and Prouse (1973). Stimulation of photosynthesis as reported by Mironov and Lanskaya (1969) and Strand, et al. (1971), was apparent only for low concentrations of the crude oil during spring. (Gordon and Prouse indicated that the highest oil concentration they had ever measured in sea water, 25 cm below a 2-day crude oil slick, was 800 μg/l.)

F-4-c. Effects on Herbivores

The existence of water-soluble petroleum hydrocarbons in the water column can also affect the ability of suspension-feeding herbivores to utilize phytoplankton. One effect is through behavioral inhibition of the herbivores' feeding process. A decrease in copepod filtering rate was surmised from a decrease in fecal pellet production by copepods exposed to an oil droplet concentration of 10 ppm for 20 hours (Spooner and Corkett 1974).

Reduction of food resources of zooplankton has the effect of reducing overall production by influencing both the occurrence of adults and their sex ratio (Conover 1965; Omori 1970). Even subtle alterations in the community structure of the primary producers available as food for the zooplankton have the potential to inhibit growth and reproduction. This is a prominent process in natural systems which has been evolutionarily accommodated by the various life history strategies exhibited by the zooplankton. The question arises, however, of the effects of changes in the available phytoplankton beyond magnitudes and time frames to which the zooplankton have adapted.

Parsons, et al. (1967), provided evidence that although zooplankton may consume a variety of foods, only a few food items may provide a satisfactory diet for growth and reproduction. Specifically, they found that the diatoms *Chaetoceros debilis* and *C. socialis* were poor food sources for three zooplankton organisms in the Strait of Georgia. Consequently, the growth rate of late stage *Calanus plumchrus* populations (an important prey of juvenile salmon) under the Fraser River plume, declined when the only food supply available consisted of small flagellates in late April (Parsons, et al., 1969).

F-4-d. Disruption of Heterotrophic Production

In the nearshore ecosystem, where the decomposition of detritus by marine microflora is an important process in the annual production of food resources available for epibenthic zooplankton and benthic meiofauna, petroleum hydrocarbons could influence the rates or timing of this conditioning process. There is little evidence to indicate that bacteria would be negatively affected by the introduction of petroleum. Hodson, et al. (1977), reported that although bacteria were the first organisms in the CEPEX enclosures to be affected by introduced oil, their rapid generation time, the diversity of strains, and their ability to mutate allowed a rapid recovery of heterotrophic activity. There is some question, however, of the possible effects of hydrocarbons on the behavior of the bacteria. Walsh and Mitchell (1973) have indicated that the chemotaxic behavior of the bacteria--i.e., the ability to detect and move to food sources--was significantly inhibited by various petroleum products and components. Such an effect, though seemingly critical, may be completely compensated for by the increased growth of sulfide-generating bacteria in response to the petroleum hydrocarbons as suitable organic matter (Colwell and Walker 1977; Karrick 1977). Westlake, et al. (1978), have illustrated that such microbial populations exist to some degree at 22 sites in north Puget Sound and along the Strait of Juan de Fuca and would logically be capable of expanding and utilizing petroleum spilled in the region. It remains to be verified, however, whether these oil-degrading bacteria would naturally utilize these detrital sources or would be acceptable to bacteria-stripping zooplankton and meiofauna.

F-4-e. Alteration of Food Resources of Consumer Organisms

The effect of food limitation upon consumers such as planktivorous fish may be even more pronounced than for zooplankton as the potential for adaptation and capability for rapid population responses tend to be more limited. For instance, the abundance and size composition of zooplankton has been suggested as critical determinants of fish survival during the transition from larval to juvenile stages (Thayer, et al., 1974). The early life histories of many economically and ecologically important fish species of the region (Pacific salmon, herring, sand lance, greenling, and smelt) include larval and juvenile stages which reside in the region's surface waters for weeks or months. At this time, their growth and ultimately their survival are in part dependent upon their achieving an adequate ration of prey organisms.

Blaxter (1965) provides evidence from Soviet investigations that reasonable survival of fish larvae requires concentrations of prey around 20,000 per m^3 and that lower survival rates would be suspected at prey concentrations less than 5,500 per m^3. LeBrasseur, et al. (1969), calculated that the waters of the Fraser River plume in the southern Strait of Georgia possessed approximately 10,000 copepods (assuming all *Microcalanus* sp.) per m^3 in early March when considerable numbers of larval fish are in the area. Plankton sampling in the Strait of Juan de Fuca (Chester, et al., 1977) suggests significantly lower abundance in that region, but they sampled no stations in the nearshore environs where zooplankton populations may be larger.

Just as important as total abundance, the size composition of the zooplankton also determines the extent of exploitation by piscivorous fish. LeBrasseur, et al. (1969), illustrated that larval fish occupying the region of the Fraser River plume in the Strait of Georgia grazed mainly on zooplankton in the 500-μ size range while juvenile fish utilized 700-μ to 2,000-μ plankters. This is not a static pattern but changes with the changes in morphology and bioenergetic demands and feeding capabilities which occur as the fish grow. For instance, Pacific sand lance (*Ammodytes hexapterus*) less than 20 mm in length feed specifically on zooplankton (nauplii and copepod eggs) less than 500 μ, while Pacific sand lance greater than 40 mm prey on zooplankton in the 500-μ to 1,000-μ range (LeBrasseur, et al., 1969).

These findings imply that since only a small portion of the available prey resource is usually exploited by predators at a particular time, any deleterious influence on this fraction, despite the maintenance of the unexploited fraction, may actually limit the production of the predator population. The principal example in the case of the neritic food webs of north Puget Sound and the Strait of Juan de Fuca is the surface layer zooplankton community which is made up primarily of small calanoid copepods (*Pseudocalanus* sp. and *Microcalanus* sp.). It is this community which is heavily utilized by larval and juvenile fish during late winter and spring and which would appear to be the most susceptible to water-borne petroleum hydrocarbons. Deepwater zooplankton, composed primarily of large calanoids, *Calanus* sp., would be less affected, and through diel vertical migrations such zooplankton would still be available to the fish. This implies, however, the necessity of the fish to switch from one prey resource, which appears to provide an optimal opportunity to gain an adequate daily ration, to one which may not be adequate. Although prey switching may be feasible (Murdoch, et al., 1975; Oaten and Murdoch 1975; Reed 1969) because of the availability of sufficient numbers of alternative prey and plastic feeding behavior of the predator, the alternative prey resources may not be optimal from the standpoint of their size, avoidance capabilities, or nutritional value. The inability to secure an adequate ration usually results in a sacrifice in growth, reproduction, or ultimately survival.

In the example just cited, the small calanoid copepods *Microcalanus* sp. and *Pseudocalanus* sp. appear to be unsuitable as a sustained food source for juvenile salmon (pink and chum) because of their size and behavior, whereas the larger copepods such as *Calanus* sp. can provide adequate rations at lower concentrations (LeBrasseur, et al., 1969). Koeller and Parsons' (1977) studies of juvenile chum salmon (*Oncorhynchus keta*) also illustrated that the young salmon had greater difficulty obtaining their required ration from small copepods (0.07-0.12 mg--such as *Pseudocalanus minutus*, *Paracalanus parvus*, *Corycaeus anglicus*) than from large copepods (0.4-2.0 mg--such as *Calanus plumchrus*, *Centropages abdominalis*), even though the smaller prey were ten times more numerous than the larger. Apparently, energy acquired from feeding on the more numerous smaller copepods was utilized for the extensive feeding activity and basic metabolism, whereas energy obtained from eating a few large copepods allowed energy in excess of basic metabolism and feeding activity to be diverted into growth. Thus, alteration of the available prey community by a pollutant introduction may have a more critical effect than the direct effect upon the predator, especially in the long run.

More important than basic somatic growth, reproduction in fishes is highly dependent on food supply. Although there is some variability in the species' strategies under the stress of inadequate ration, most investigators have found reproduction parameters--numbers of spawnings, percentage of population reproducing, total egg production, percentage of ovarian oocytes with yolk, post-spawning survival--are directly correlated with ration level (Bagenal 1969; Scott 1962; Tyler and Dunn 1976; Wootton 1977). Thus, if a pollutant alters the food supply of a significant portion of the reproductive population in one year, the production of that year class will be affected for several years thereafter.

F-4-f. Effects of Removal or Reduction of Keystone Species

While disruption of the food web structure by impacts at the lower trophic levels is likely, just as likely is disruption of the community structure by selective mortality or severe sublethal effects on keystone species at higher trophic levels. Seastars (*Pisaster* sp, *Leptasterias* sp.), sea urchins (*Strongylocentrotus* sp.), predatory gastropods (*Thais* sp.), and large infaunal bivalves (*Tapes* sp., *Mya* sp.) typically have very low recruitment rates, and so removal or dramatic reduction of these species would probably result in a sustained modification of the nearshore community structure for years or decades. Such community disruption has the potential to dramatically affect production of macrophytic algae, a major component of the detritus-based food webs.

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APPENDIX G
BIOENERGETIC MODEL OF THE EPIBENTHIC FOOD WEB IN THE MUD/EELGRASS SHALLOW SUBLITTORAL HABITAT AT WESTCOTT BAY

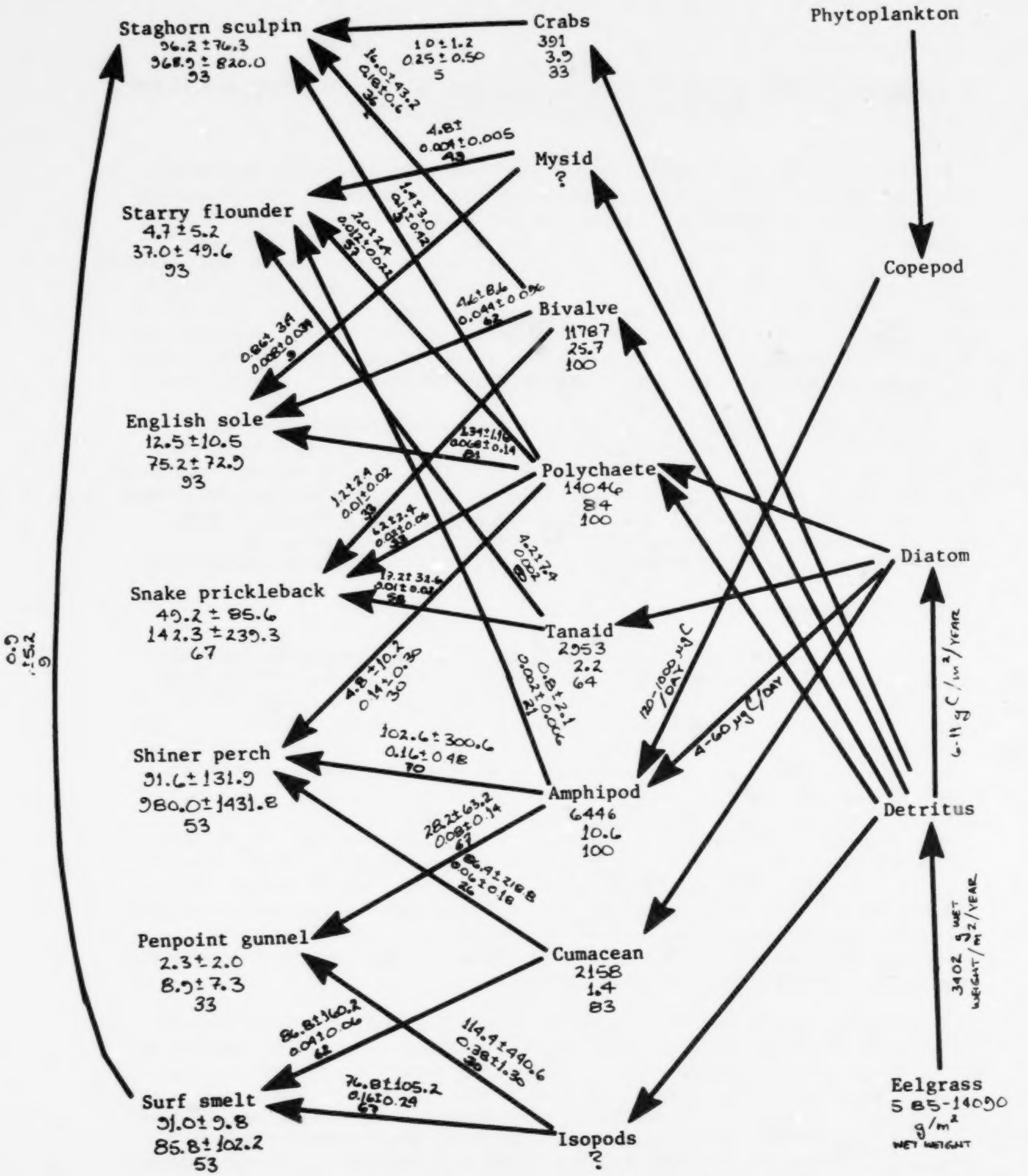
A simplified bioenergetic model was constructed for one nearshore site in northern Puget Sound for which we had the most reliable quantitative data--the relatively enclosed, mud/eelgrass embayment habitat at Westcott Bay on the northwestern coast of San Juan Island. The epibenthic food web was emphasized because we had community and trophic data on the epibenthic and demersal fish and invertebrate communities (Miller, et al., 1977; Nyblade 1978) and fairly meager, unquantitative data on food webs of infauna communities. We recognize that such an approach has little applicability to the Westcott Bay system as a whole, and much less to other mud/eelgrass, contained embayment habitats in north Puget Sound.

Food web data have been summarized in a very simplified diagram (Appendix Fig. G-1) where population abundance (mean ± 1 s.d.), biomass (mean ± 1 s.d.), and frequency of occurrence over time have been estimated for the nodes of the web. Transfer rates between nodes include the number of prey consumed (mean ± 1 s.d.), the biomass consumed (mean ± 1 s.d.), and the frequency of consumption. In addition, growth rates were estimated for secondary consumers in order to calculate node production.

Primary Production

Many herbivores are present in tropical marine waters but not in temperate-water habitats such as Westcott Bay. In a Nova Scotian kelp community, Mann (1973) found that herbivores consume less than 10% of the primary production and 90% entered detritus food chains. Thayer, et al. (1975), found detritus deposition rates in eelgrass beds to be 12-22 mm per year and this was either utilized as food in the system or exported. Harrison and Mann (1975) showed that eelgrass detritus provides a better food source than dead intact leaves because there is a rise in the percentage of nitrogen during bacterial decomposition. The assimilation efficiency of detritus by macrofauna in eelgrass beds has been estimated at 46%-48% (Adams and Angelovic 1970). As has been shown in this report, it is evident that detritus input from eelgrass and macroalgae forms the base of the nearshore food webs in coastal marine ecosystems. The relative importance of pelagic primary production has not been accurately assessed in nearshore ecosystems, however.

Standing stock and production of macroalgae and rooted vegetation have been estimated in many areas (Appendix Table G-1). Four categories of primary energy sources were identified in Westcott Bay: Plankton, rooted macrophytes (eelgrass), epiphytic and epibenthic algae, and macroalgae. McRoy (1977) estimates that epiphyte dry weight equals that of leaf dry weight in eelgrass beds. Based on literature estimates, standing crop and production were estimated for the primary energy sources in Westcott Bay (Appendix Table G-2). The production of epiphytic algae, a principal energy source for grazers, was estimated with less confidence.


Staghorn sculpin
96.2 ± 76.3
968.9 ± 820.0
93
Crabs
391
3.9
33
1.0 ± 1.2
0.25 ± 0.50
5
Phytoplankton
16.0 ± 43.2
0.18 ± 0.6
36
4.8 ±
0.001 ± 0.005
43
Mysid
?
Starry flounder
4.7 ± 5.2
37.0 ± 49.6
93
1.4 ± 3.0
0.1 ± 0.42
3
2.0 ± 2.4
0.012 ± 0.022
57
Copepod
4.6 ± 8.6
0.044 ± 0.096
62
Bivalve
11787
25.7
100
0.86 ± 3.4
0.008 ± 0.039
9
English sole
12.5 ± 10.5
75.2 ± 72.9
93
1.34 ± 1.10
0.068 ± 0.14
81
Polychaete
14046
84
100
1.2 ± 2.4
0.01 ± 0.02
33
6.2 ± 2.4
0.02 ± 0.06
33
4.2 ± 7.4
0.002
80
17.2 ± 32.6
0.01 ± 0.02
58
Diatom
Snake prickleback
49.2 ± 85.6
142.3 ± 239.3
67
Tanaid
2953
2.2
64
0.9
±5.2
9
120-1000 µgC
/DAY
6-11 g C/m²/YEAR
4.8 ± 10.2
0.14 ± 0.38
30
0.8 ± 2.1
0.002 ± 0.006
21
4-60 µg C/DAY
102.6 ± 300.6
0.16 ± 0.48
70
Shiner perch
91.6 ± 131.9
980.0 ± 1431.8
53
Amphipod
6446
10.6
100
Detritus
28.2 ± 63.2
0.08 ± 0.14
67
86.4 ± 218.8
0.06 ± 0.18
26
3402 g WET WEIGHT/m²/YEAR
Penpoint gunnel
2.3 ± 2.0
8.9 ± 7.3
33
Cumacean
2158
1.4
83
86.8 ± 160.2
0.04 ± 0.06
62
114.9 ± 440.6
0.38 ± 1.30
30
76.8 ± 105.2
0.16 ± 0.29
67
Eelgrass
585-14090
g/m²
WET WEIGHT
Surf smelt
91.0 ± 9.8
85.8 ± 102.2
53
Isopods
?

Appendix Fig. C-1. Bioenergetic food web model of epibenthic community of Westcott Bay. Fish population and consumption data were obtained in a 900-m^2 sampling area. Node and linkage values are, from top to bottom, number m^{-1}, grams m^{-1}, and % frequency of occurrence.

Appendix Table G-1. Standing stock and primary production in coastal detritus-based system. Numbers have been converted to g/m^2 wet weight.

System	Standing stock	Production
Eelgrass, Alaska (McRoy 1970)	585-13,590 g/m^2	243 g/m^2/day
Eelgrass, Denmark August (Sand-Jensen 1975)	3,987 g/m^2	9,900 g/m^2/yr
Brown algae, Nova Scotia (Mann 1973)	2,001 g/m^2	13,000 g/m^2/yr
Eelgrass, North Carolina		
Detritus	46,000 g/m^2	
Primary production (Thayer, et al., 1975)		3,400 g/m^2/yr
Eelgrass, Scotland		
Plankton		2,085 g/m2/yr
Substrate-primary production (McIntyre and Eleftheriou 1968)		88-197 g/m^2/yr

Appendix Table G-2. Estimated primary energy sources (wet weights) in Westcott Bay, San Juan Island. Values are annual means.

Source	Standing crop g/m^2	Annual production g/m^2
Phytoplankton	14	560
Rooted macrophytes	2,500	1,740-9,900
Epiphytic and epibenthic algae	2,000	20,000
Macroalgae	200	2,000

Each of these four primary production compartments contributes energy to grazers, detritus, and dissolved organic matter. These flows were estimated for Westcott Bay as contributions to annual production (Appendix Fig. G-2). In the absence of any quantitative data the detritus in eelgrass beds was considered simply as steady state with no net erosion or accumulation necessary to maintain the bed. This provides a first-order estimate of detritus available to fish predators through detritivorous prey, but may grossly underestimate the total amount of organic carbon (such as dissolved organic carbon) which is contributed to the food web by eelgrass.

Primary Consumers

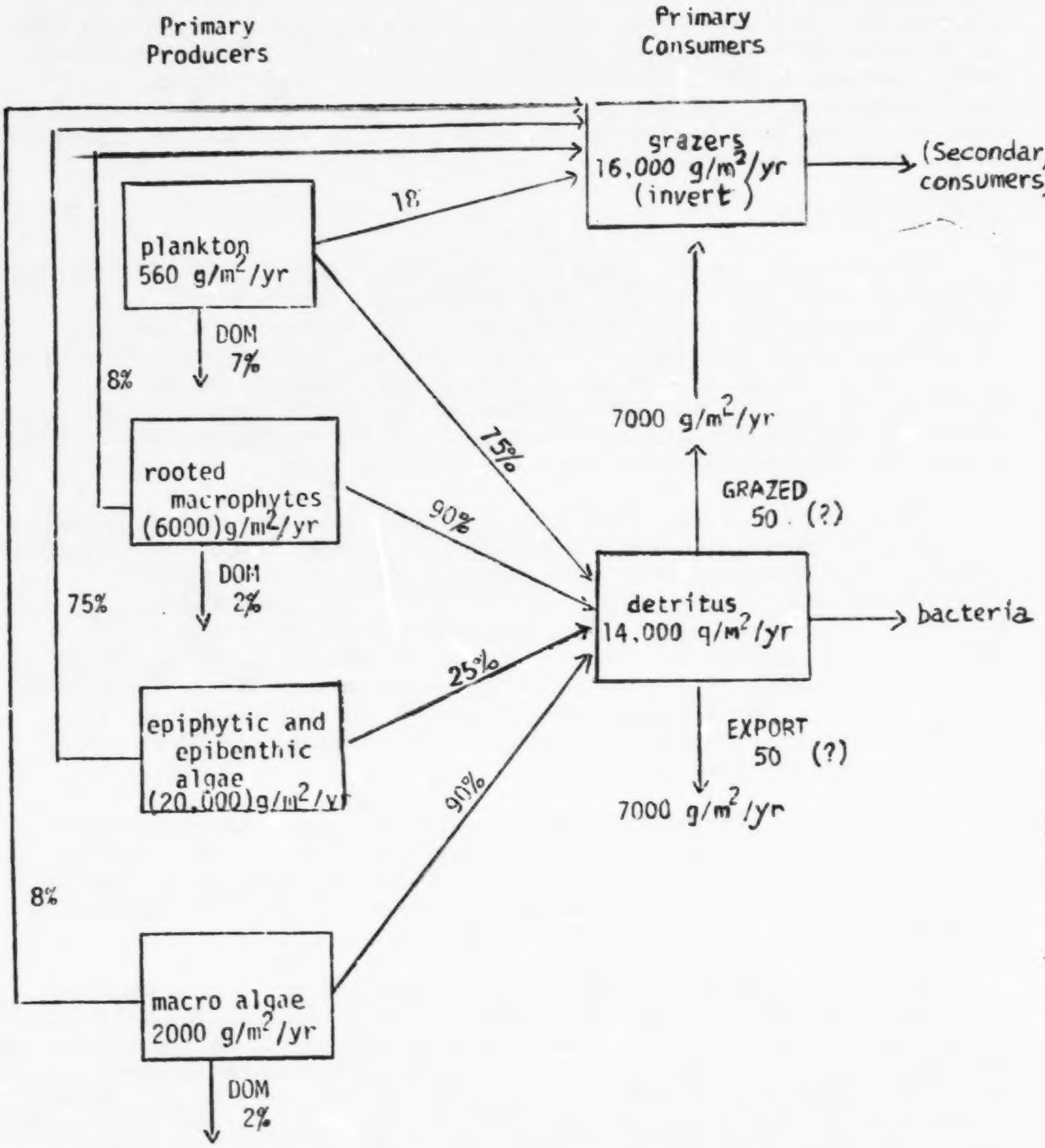
The primary consumers form the important energy link between primary production and higher trophic level carnivores. Brook (1977) in a Florida eelgrass bed found that polychaete and epibenthic crustacean populations limit the fish predator population. Most high trophic level carnivores in eelgrass beds are at least partly benthic predators. McIntyre and Eleftheriou (1968) estimated the benthic meiofauna standing crop in a flatfish nursery to be 1.25 g C m^{-2} dry weight and the annual production was approximately twice the standing crop.

The primary consumer level may be divided into two classes based on feeding mode--suspension feeders and deposit feeders. A loss of organic matter to the system at this level may be caused by maintenance, inefficient ingestion processes, production of pelagic gametes, and conversion of organic matter into unusable elements (Levington 1972). Selectivity in feeding by size and energy content of particles was shown for a deposit-feeding bivalve (Hylleberg and Gallucci 1975). Brinkhurst, et al. (1972), found the same two criteria in particle selection for a tube-building oligochaete and they estimated respiration and growth to be 84.5 kcal/g annually.

Feller (1977) estimated production and standing crop of benthic harpacticoid copepods to be 1 g C m^{-2} yr^{-1} and 10^6 m^{-2}, respectively. The standing crop estimate is a summer maximum and it is much lower in the winter. Cohorts took six months to mature and the instantaneous daily population increase was -0.3 to 2.2.

Dagg (1975) estimated carbon and nitrogen budgets for an amphipod which feeds on both diatoms and copepods. The younger individuals are primary consumers and they switch to a more carnivorous diet with age. The assimilation efficiencies of both carbon and nitrogen ingestion were 90%. Dagg found this higher than assimilation efficiencies for other carnivorous aquatic invertebrates: Polychaetes, 82-89%, euphausiids, 84%. Ingestion rates increased when the amphipod switched from diatoms to copepods. The daily ingestion rates on diatoms were 4-60 g C and 0.7-12 g N and copepod ingestion rates were 120-1,000 g C and 40-190 g N.

Population information for the primary consumers in Westcott Bay was derived from subtidal core samples and epibenthic pumping.


Primary Producers
Primary Consumers
grazers
16,000 g/m2/yr
(invert)
(Secondary consumers)
plankton
560 g/m2/yr
18
DOM
7%
8%
75%
rooted macrophytes
(6000)g/m2/yr
90%
DOM
2%
75%
7000 g/m2/yr
GRAZED
50 (?)
detritus
14,000 g/m2/yr
bacteria
25%
epiphytic and epibenthic algae
(20,000)g/m2/yr
EXPORT
50 (?)
7000 g/m2/yr
90%
8%
macro algae
2000 g/m2/yr
DOM
2%

Appendix Fig. G-2. Estimated flows to detritus, grazed and dissolved organic matter (DOM) compartments from primary production compartments.

Secondary Consumers

More detailed information is available for population at the secondary consumer level than at any other. Beach seine and stomach analysis data from Westcott Bay were collected from July 1974 to September 1975 (Miller, et al., 1976). Seasonal growth rates and conversion efficiencies are estimated for the dominant species, staghorn sculpin and juvenile flatfish (Appendix Table G-3). The growth rate varies from 0.01 to 0.86 g day^{-1} and the maximum is in juvenile flatfish in early summer decreasing as they grow during the summer. Based on a 200-day growing season and growth rate of 0.08 g day^{-1}, the annual production of secondary consumers in Westcott Bay was estimated (Appendix Table G-4).

Estimate of Daily Rations of Fishes

Detailed stomach content analysis was available for most secondary consumer species but the number of stomachfuls ingested per day was unknown. Some demersal and schooling neritic fish are believed to forage at dawn and dusk (Hobson 1975; Cooney 1967). If the stomach is filled during each of these activity periods, then an ingestion rate may be calculated based on two stomachfuls per day, although as we shall see this may be an underestimate. This assumption has been used for estimating ingestion rates in this study.

Three modes of feeding are exhibited by the secondary consumers in Westcott Bay. The first group are the pelagic feeders, composed of Pacific herring and Pacific sand lance. This feeding is driven by neritic production. This group is very abundant numerically and is subject to heavy predation by birds and larger fish. The second group, to which perch belong, are epifaunal feeders. This feeding mode is driven by eelgrass production with a time lag for settlement and growth of epifauna. Bottom feeders are the third and largest category, comprising starry flounder, English sole, gunnel, prickleback, and surf smelt. The top predator, staghorn sculpin, switches opportunistically between benthic feeding and feeding on pelagic fish.

Seasonal variability in growth rate and conversion efficiency is quite high. As may be expected in a nursery area, seasonal changes in biomass are also high at this trophic level. Monthly estimates of secondary consumer standing crop for Westcott Bay are shown in Appendix Table G-5. From core samples and stomach analysis, there is also evidence for seasonal switching of prey by English sole which follows changing prey availability (Thornburgh 1978), although high variability may obscure the trends. The same predator's diet changes significantly between the two sites. With this very high seasonal variability in growth rate, conversion efficiency, standing crop, and diet, it is clear that initial food web models should be limited to season, or separately iterated over each season.

Anomalies in the Westcott Bay food web are apparent, even at the highest trophic level where the data were assumed to be the most precise. To assess the accuracy of estimates of annual production of secondary consumers, yearly food intake of English sole was compared with its

Appendix Table G-3. Seasonal growth rates and conversion efficiencies, Westcott Bay.

		Daily weight change (g)	Daily intake (g)	Conversion efficiency (weight change) intake (%)
Staghorn sculpin	Apr-May	0.02	0.36 ± 0.36	6
	July-Aug	0.13	1.34 ± 2.56	10
	Aug-Sept	0.90	3.42 ± 9.12	3
	Sept-Oct	0.05		
English sole	Mar-Apr	0.01	0.06 ± 0.04	17
	Apr-Jun	0.07	0.24 ± 0.20	29
	July-Sept	0.07	0.78 ± 3.42	9
	Sept-Oct	0.13		
Starry flounder	July-Aug	0.03		
	Aug-Sept	0.05	0.24 ± 0.40	21
	Sept-Oct	0.20		

Appendix Table G-4. Estimated annual production (wet weights) of secondary consumers in Westcott Bay, San Juan Island.

Species	Annual production, g/m^2
Staghorn sculpin	2.10
Starry flounder	0.09
English sole	2.10
Snake prickleback	0.90
Shiner perch	1.60
Penpoint gunnel	0.02
Surf smelt	1.60
Total	8.41

Appendix Table G-5. Seasonal changes in standing crop of secondary consumers at Westcott Bay, given in grams per square meter.

July 1974	4.09
August	1.11
September	4.16
October	3.80
November	1.71
December	0.91
January 1975	0.24
February	0.13
March	0.04
April	0.13
May	0.20
June	
July	0.87
August	0.94
September	6.60

production. For an annual production of 2.1 g m^{-2} and 10% growth efficiency, English sole would have to consume 21 g m^{-2} yr^{-1}. Annual consumption rates estimated from daily consumption are 0.35-0.50 g m^{-2} yr^{-1}. This error factor of 40-50 shows that more information is still necessary even at the level of higher consumers. Possible sources of error are: (1) Daily intake rate of two stomachfuls is too low for rapidly growing juveniles. (2) Ten percent growth efficiency is too high. (3) Mean growth rate is too high--it may be nearer the low end of the range during most of the growing season. (4) Intake estimates from partly digested stomach samples are too low. (5) Population biomass estimates are in error. These feeding and growth rates could be more accurately measured by laboratory studies.

If such great discrepancies exist between feeding and growth rates at high trophic level, even greater errors may be expected for the primary consumers where less quantitative data were available. Metabolic studies have been conducted for several species of amphipods (Chang and Parsons 1975; Halcrow and Boyd 1967). Information on particle selection and assimilation efficiency is also known for species of various taxa. However, this knowledge is quite patchy. A concentrated effort on the primary consumers of an area must be undertaken to estimate standing crop, feeding and growth rates, and production.

An important subsystem of Westcott Bay was overlooked initially in efforts to simplify the system. This food web consists of the large macroinvertebrates such as starfish, bivalves, crabs, and anemones that are typical of most eelgrass areas. These macroinvertebrates are suspension feeders, macroalgae grazers, and carnivores, and therefore represent unaccounted for nodes and linkages in the food web. A comprehensive bioenergetics analysis of any habitat as a whole will have to incorporate every component system despite its complexity.

It is assumed that after identifying and quantifying the principal energy pathways in a food web, the effects of perturbations can be better assessed. Three possible outcomes of a perturbation are possible for a population: (1) Population numbers decrease, (2) population numbers remain constant but the mean weight per individual decreases, (3) the population dies or leaves the area. Knowing the mobility of the population and the ability of individuals to switch to different prey, as well as the basic information on growth and feeding rates and production, would be necessary to predict the outcome.

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